The Journal

OF THE

Royal Aeronautical Society

With which is incorporated The Institution of Aeronautical Engineers

A Monthly Illustrated Magazine devoted to all subjects connected with the Navigation of the Air.

EDITED FOR THE

COUNCIL OF THE ROYAL AËRONAUTICAL SOCIETY

BY

Captain J. LAURENCE PRITCHARD, Hon. Fellow.

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THE ROYAL AERONAUTICAL SOCIETY

(Founded 1866*)*

with which is incorporated the Institution of Aeronautical Engineers

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VOLUME XLIV

MONTHLY NOTICES,

JANUARY, 1940.

The New Year.

The President (Mr. A. H. R. Fedden), the Vice-Presidents (Mr. Griffith Brewer and Air Vice-Marshal R. M. Hill) and the Council wish all Members of the Society a Happy and Prosperous 1940.

Office Hours.

From Saturday, January 13th, 1940, the office hours will be from 9.30 a.m. to 5 p.m. from Monday to Friday and from 9.30 a.m. to 12.30 p.m. on Saturdays. The Library will be open during office hours and also on Saturday afternoons from 2 p.m. to 5 p.m.

Special General Meeting.

NOTICE IS HEREBY GIVEN that a Special General Meeting under Rule 108, of the Royal Aeronautical Society, with which is incorporated the Institution of Aeronautical Engineers, will be held on Saturday, January 27th, 1940, at 5.30 p.m., in the Offices of the Society at No. 4, Hamilton Place, W.1, to consider alterations to and additions to the Rules.

Particulars of the proposed alterations and additions to the Rules will be sent to all voting members of the Society through the post.

Meeting of Council.

A Meeting of Council was held at No. 4, Hamilton Place, W.1, on Thursday, December 14th, 1939, when the following members were present:—

Mr. A. H. R. Fedden (President) in the chair; Captain P. D. Acland, Professor L. Bairstow, Mr. Griffith Brewer (Vice-President), Mr. S. Camm, Mr. D. L. Ellis, Professor F. T. Hill, Mr. J. E. Hodgson (Honorary Librarian), Major D. H. Kennedy (Honorary Treasurer), Lieut.-Colonel W. Lockwood Marsh, Dr. H. C. Watts.

Among the business discussed was the following:—Wilbur Wright Memorial Lecture, 1940, and other lectures; Alterations of Rules; Annual Subscriptions; Education; Military Service and Aeronautical Engineering Training.

Donations to the Society.

On pages 7-11 appear the President's letter sent to every member shortly following the outbreak of war, followed by a list of donations to the Endowment Fund of the Society.

The President and Council wish to place on record their great appreciation of the generosity of so many firms and individuals in the industry. For many years the Council have been deeply concerned with raising an adequate Endowment Fund which would provide an income for the upkeep of a suitable headquarters for the oldest aeronautical society in the world, and also provide a sufficient income to allow the Council to proceed along progressive lines for the benefit of members.

Most of the donations are in the form of seven-year donations, so that it will not be until 1946 that the full sum will be realised and the corresponding income added to the Society.

Graduates and Students Section.

An Informal Meeting of Graduates and Students will be held on January 20th in the Offices of the Society at 4, Hamilton Place, W.1, between 2 p.m. and 4 p.m. Refreshments will be available and Graduates and Students are welcome at any time during the afternoon. Aeronautical matters generally will be discussed.

Bachelor of Science Degree.

The rapid increase in the importance of aeronautical engineering, and the very definite specialisation required, beyond a certain point, led the Council to consider very carefully to what extent aeronautical subjects should be included in engineering examinations for those students who intended, ultimately, to become aeronautical engineers.

It is generally known, following representations of the Society, that National Certificates and Diplomas are endorsed by the President of the Society for Aircraft Engineering, and that for some time questions on aeronautical engineering have been included in the B.Sc. (Eng.) examinations at the University of London.

At the beginning of 1939 the Council were of the opinion that the time had now arrived when aeronautical engineering should be put on the same footing as civil, mechanical and electrical engineering, as far as regards a degree course.

A memorandum stating the reasons for the Council's opinion was addressed to the Academic Registrar at the University of London on the subject of the training of aeronautical engineers and a reply was received that the Board of the Faculty of Engineering would be glad to meet representatives of the Society to discuss the matter fully.

The following were appointed to represent the Society:—

Mr. A. H. R. Fedden, President.
Mr. S. Camm, Member of Council.
Dr. N. A. V. Piercy, Member of Council.
Mr. H. E. Wimperis, Immediate Past-President.
Captain J. Laurence Pritchard, Secretary.

At the meeting with the Board, Mr. Fedden, the President, and Mr. Wimperis, the Immediate Past-President, briefly explained a number of points in the Society's memorandum, and the urgent need for further facilities for aeronautical engineering training, and answered points raised by the Board of the Faculty of Engineering.

At the end of July, 1939, the following letter was received by the Society, addressed to the Secretary:—

"Dear Sir,

With reference to your letter of December 28th, 1938, I now write to inform you that the Senate at their meeting yesterday resolved that aeronautics be included in the Course for Part II of the Bachelor of Science (Eng.) Examination in the same way as civil, mechanical and electrical engineering are already included in that course.

The question of drawing up regulations is being submitted to the appropriate board of studies.

Yours faithfully,
S. I. WORSLEY,
Academic Registrar."

The regulations referred to in this letter will be published in the Journal in due course. The President and Council, naturally, view with satisfaction the result of their efforts, a result due not only to the important position now reached by aeronautical engineering, but due also to the very sympathetic hearing given to the representatives of the Society by the Board of the Faculty of Engineering at the University of London, under the chairmanship of Professor G. T. R. Hill.

The President and Council have had every aspect of the training of aeronautical engineering under close review during the past twelve months. In many direc-

tions they are pressing for a fuller recognition of the importance of training men (and for providing full facilities for training) now for the future increase in developments which are clearly coming.

Election of Members.

The following members were recently elected:—

Associate Fellows.—Leslie Richard Eyre Appleton (from Graduate), George Beaumont, Donald Clifford Tyndall Bennett, Jack Halliwell (from Student), Arthur Leslie Haslam (from Associate), Gilbert Frederick William Roper (from Student), Howard Charles Sheath.

Associates.—Harin Hongskula, Krishna Lakshman Shenoy.

Graduates.—John Charles Barr, Keith Beaumont Chamberlain, Stanley Dearing, John Chevalier Hardman (from Student), Leighton Stuart Holt (from Student), William Geoffrey Perrett, Francis Norbert Regan.

Students.—Kenneth Harold Brend, Peter Charles Cleaver, Edmund William Coates, Alexander Stanley Eakins, Walter Frame Gibb, James Philip Lloyd Gwyther, John Hind, Kenneth Henry Jenkins, George Douglas Gergay Ostroumoff, John Garry Owen, Richard James Packman, Grahame Herbert Pearce, George Frederick Pitts, William Samuel Pollinger, Clive Thomas James Ware, Donald Frederick Youldon.

Companions.—Francis Henry Ballinger, John Thomas Bolas, James Falcke, James Hood, Richard Conrad Kernick.

Members' Subscriptions.

Members are reminded that their subscriptions are due on January 1st, 1940. The Council hope that every member will make every effort to pay his subscription as early as possible. The rates are:—

	Home. £ s. d.	Abroad. £ s. d.
Founder Member	2 2 0	2 2 0
Fellow	4 4 0	3 3 0
Member	4 4 0	3 3 0
Associate Fellow	3 3 0	2 2 0
Associate Member	3 3 0	2 2 0
Associate	*2 2 0	*2 2 0
Graduate	2 2 0 (21-26 years)	
	2 12 6 (26-28 years)	
Student	1 1 0	1 1 0
Companion	2 2 0	2 2 0

* £1 1s. 0d. without JOURNAL.

Emergency Address.

During the period of the war correspondence may be addressed either to headquarters or to the Society's country address, Brook House, Old School Lane, Brockham. (Telephone Betchworth 189.)

Acknowledgments.

The Council acknowledge with grateful thanks gifts of books for the Library from Mr. Griffith Brewer, Miss L. Chitty (Fellow), Mr. N. Hollyhock, Mr. V. Hunt and Mr. A. R. Weyl. Mr. Griffith Brewer has, in particular, presented the library with a copy of Bishop Wilkins' book "Mathematical Magick" and with a number of contemporary coloured pictures of aircraft of the period 1908-9.

We regret that by an oversight the list of British Standard Specifications received during 1939 was omitted from our Additions to Library in the December Journal. These specifications are listed in the current Additions to Library.

Additions to Library.

Aeronautical Research Committee: Reports and Memoranda:—

No. 1842. Measurements of the Intensity and Scale of Turbulence. By A. A. Hall. 5/-.

No. 1844. Flight Tests on Wing Sections Using the Parasol Monoplane. By the Aerodynamics Staff, R.A.E. 3/-.

No. 1854. Tests on a 16% Handley Page Aerofoil with 20% Slotted Flap in the Compressed Air Tunnel. By D. H. Williams, A. H. Bell and E. Smyth. 2/6.

No. 1861. The Effect of Ground Interference on the Trim of a Low Wing Monoplane. By H. M. Lyon and J. E. Adamson. 4/-.

British Standard Specifications (received during 1939 from British Standards Institution):—

A.14. Hexagonal Brass Nuts for Aircraft Purposes. 1/-.

A.15. Hexagonal Headed Bolts (High Tensile Steel) for Aircraft Purposes. 1/-.

A.16. Hexagonal Steel Nuts (ordinary, thin, slotted and castle) for Aircraft Purposes. 1/-.

5A.1. Hexagonal Headed Bolts (Low Tensile Steel) for Aircraft Purposes. 1/-.

E.18. Electric Incandescent Lamps for Aircraft (Landing Lamps). 1/-.

3E.12. Electric Incandescent Lamps for Aircraft (other than Landing Lamps). 1/-.

3F.50. Eyeleted Fuselage Webbing for Aircraft Purposes. 1/-.

2L.38. Aluminium Coated Aluminium Alloy Sheets and Coils for Aircraft Purposes. (Specific gravity not greater than 2.85.) 1/-.

5L.3. Aluminium Alloy Sheets and Coils for Aircraft Purposes. (Specific gravity not greater than 2.85.) 1/-.

S.P.8. Turnbuckles (Tension Rod Type) for Aircraft Purposes.

4T.47. Brass Tubes for Honeycomb Type Radiators for Aircraft Purposes. 1/-.

National Advisory Committee for Aeronautics: Reports:—

No. 661. Tests in the Variable Density Wind Tunnel of the N.A.C.A. 23012 Airfoil with Plain and Split Flaps. By I. H. Abbott and Harry Greenberg.

No. 662. Design of N.A.C.A. Cowlings for Radial Air-Cooled Engines. By George W. Stickle.

No. 667. Determination of the Profile Drag of an Airplane Wing in Flight at High Reynolds Numbers. By Joseph Bicknell.

No. 670. Tensile Elastic Properties of 18:8 Chromium-Nickel Steel as affected by Plastic Deformation. By D. J. McAdam, Jr., and R. W. Mebs.

National Advisory Committee for Aeronautics: Technical Notes:—

No. 716. Hydrodynamic and Aerodynamic Tests of a Family of Models of Seaplane Floats with varying Angles of Dead Rise. By J. B. Parkinson, R. E. Olson and R. O. House.

No. 717. A Method of Estimating the Critical Buckling Load for Structural Members. By E. E. Lundquist.

No. 718. Resistance of Transparent Plastics to Impact. By B. M. Axilrod and G. M. Kline.

No. 719. The Effects of Partial Span Slotted Flaps on the Aerodynamic Characteristics of a Rectangular and a Tapered N.A.C.A. 23012 Wing. By Rufus O. House.

No. 720. Flight Tests of N.A.C.A. Nose-Slot Cowlings on the BFC-1 Airplane. By George W. Stickle.

No. 721. Compressive Tests of a Monocoque Box. By W. Ramberg, A. E. McPherson and Sam Levy.

No. 722. Local Instability of Centrally Loaded Columns of Channel Section and Z-Section. By Eugene E. Lundquist.

No. 723. Adhesion of Ice in its Relation to the De-Icing of Airplanes. By A. M. Rothrock and R. F. Selden.

School of Engineering Research, University of Toronto: Bulletins:—

No. 153. St. Andrew's Church, Niagara-on-the-Lake. By E. R. Arthur. (1938.)

Institute of Physical and Chemical Research, Tokyo:—
Scientific Papers Nos. 931-938. Various Authors.

India Meteorological Department: Memoirs:—

Vol. XXVII, Part 2. Discussion of Results of Sounding Balloon Ascents at Madras in the months of June to November during 1932-35. By N. K. Sur and K. P. Ramakrishnan. Manager of Publications, Delhi. 1/3. (1939.)

Atti di Guidonia. (Editoriale Aeronautica, Rome):—

No. 4. Una Proprietà del Meccanismo Manovella-Biella-Stantuffo e sue Applicazioni al Meccanismo a Biella Madre e Bielletta. By Prof. L. Crocco.

No. 5. Sul Calcolo delle Fusoliere a Traliccio. By Dr. C. Riparbelli.

No. 6. Il Bacino della Vasca Idrodinamica di Guidonia. By Prof. C. Cremona.

No. 7. Una caratteristica Trasformazione delle Equazioni dello Strato Limite nei Gas. By Prof. L. Crocco.

No. 12. Un nuovo Calcolo a Torsione per Strutture Alari. By Dr. Luigi Broglio.

No. 13. Il Laboratorio Aerodinamico di Guidonia. By Prof. Antonio Eula.

U.S. Works Projects Administration, N.Y.:—

Subject Index to Aeronautical Periodical Literature and Reports for 1938.

Institution of Mechanical Engineers: Proceedings, Vol. 141 (Jan.-June, 1939).

Associazione Italiana di Aerotecnica: II V° Convegno Interprovinciale di Aerotecnica, Napoli, 19-22 Maggio, 1938. Istituto Poligrafico dello Stato, Rome. 1939.

Ministry of Information: Pamphlet No. 1. The Outbreak of War (22nd August-3rd September, 1939).

National Physical Laboratory: Abstracts of Papers, 1938.

Rijks-Studiedienst voor de Luchvaart: Verslagen en Verhandelingen van het Nationaal Luchtvaartlaboratorium, Amsterdam (VIII). 1939.

Aircraft Engine Maintenance. By D. H. Brimm and H. E. Boggess. Pitman's. 1939. 10/6.

Aero Engines: Inspection of, during Manufacture, Overhaul and Test. ("D" Licence.) 6th Edition. A. N. Barrett. Sir Isaac Pitman and Sons. 1939. 3/6.

L'Aéroplane des Frères Wright. Published by Berger-Levrault, Paris. 1908. Fr. 1.00.

The Air Navigator's Self-Examining Handbook. By E. Brook Williams and W. J. V. Branch. Brown, Son and Ferguson. 1939. 10/6.

Bezeichnungen einzelner Zellenteile von Flugzeugen. (Nomenclature of Aircraft Units.) Flugzeugmeisterei A5, Adlershof.

Bulletin de la Chambre Syndicale des Industries Aéronautiques. Mai-Juin, 1927.

Col Krassin alla Tenda Rossa. By Davide Guidici. Nicola Moneta, Milan. 1929.

Commissione d'Indagini per la Spedizione Polare dell'Aeronave "Italia." Ministero della Marina, Rome. Rivista Marittima. Lire 5.50. 1930.

Con gli Alpini all' 80° Parallelo. By Capitano Sora. Mondadori, Milan. 1929. Lire 15.

Die Deutsche Luftfahrt-Wirtschaft als Gesamtprobleme. (Pamphlet.) By G. Sachsenberg. Röderdruck, Leipzig. (Abt. 1928.)

En Avion vers le Pôle Nord. By Roald Amundsen. Albin Michel, Paris. 1926. Frs. 12.

A Handbook of Empire Timbers. (Ed. by H. A. Cox.) Department of Scientific and Industrial Research. 1939. 3/6.

A Handbook of Home-Grown Timbers. (2nd Edition.) Department of Scientific and Industrial Research. 1939. 2/-.

L'Inferno Bianco. By Cesco Tomaselli. Edizioni Unitas, Milan. 1929.

Inspection of Aircraft after Overhaul. ("B" Licence.) 4th Edition. By S. J. Norton. Sir Isaac Pitman and Sons. 1939. 3/6.

L'Italia au Pôle Nord. By Umberto Nobile. Editions de la Madeleine, Paris. 1933.

The Machining of Copper and its Alloys. (C.D.A. Publication No. 34.) Copper Development Association. 1939.

Mathematical Magick. By Bishop J. Wilkins. Richard Baldwin, London. 1691.

Mechanics Applied to Vibrations and Balancing. By D. Laugharne Thornton. Chapman and Hall. 1939. 36/-.

Mr. Tompkins in Wonderland. By G. Gamow. Cambridge University Press. 1939. 7/6.

Nature Parade. By Frank W. Lane. Jarrolds. 1939. 15/-.

Patent No. 3238: "Improvements in Aerial Navigation and in Apparatus for Effecting the Same." By Thomas Moy. Patent Office. 1871.

Patents for Inventions. Abridgments of Specifications: Group XXXIII, Nos. 480,001-500,000. Patent Office. 1939. 2/-.

The Polar Adventure. By Odd Arnesen. Victor Gollancz. 1929. 12/6.

Quadrilingual Aviation Phrase Book (English, French, Spanish, German). By H. J. Day. Gale and Polden. 1939. 5/-.

Quarantotto Giorni sul "Pack." By Alfredo Viglieri. Mondadori, Milan. 1929. Lire 15.

Le R. 101 sur Beauvais Route des Indes. By Jean Ajalbert. Editions des Portiques. Frs. 12. 1931.

La Route de l'Air. By A. Berget. Hachette and Cie., Paris. 1909.

The Royal Air Force. (Revised Edition.) By Captain A. O. Pollard. Hutchinson and Co. 1939. 7/6.

I Segreti di Umberto Nobile. By Marcello Gallian. Casa Editrice Pinciana, Rome. 1928. Lire 20.

Souvenir of the Visit of Their Majesties King George VI and Queen Elizabeth to the Works of Short Bros. (Rochester and Bedford), Ltd., Rochester. (March 14, 1939.) Short Bros., Ltd.

Le Vol des Oiseaux. E. J. Marey. G. Masson, Paris. 1890.

Wind, Sand and Stars. By A. de Saint-Exupéry. Wm. Heinemann. 1939. 10/6.

"The Aeroplane" (Magazine). Bound Volumes, 1916.

"The Aircraft Engineer." (Supplement to "Flight.") Bound Volume, 1926. Unbound numbers, 1927-38.

J. Laurence Pritchard, *Secretary and Editor.*

PRESIDENT'S LETTER.

1939.

DEAR SIR,—Early this year the Council decided that annually the newly elected President should open the Autumn Session by an address, and it was to have been my great privilege to be the first to give such an address in October of this year. In this talk I had hoped to tell you something of the Council's intentions for the ensuing fifteen months.

It was hoped that next year would prove to be an important one in the history of the Royal Aeronautical Society. It had acquired new premises worthy of its prestige; it had an assured income for their maintenance, and it had decided upon holding an International Congress at Stratford-on-Avon in the summer of 1940. The Society would, therefore, assuredly take another step forward in its history of achievement.

But the coming of war has, of course, changed all this. The Council have now decided that I should write you a letter explaining what its action has been and the general policy upon which it has decided since the outbreak of hostilities.

It is appreciated that practically every member of the Society or their relatives will be playing some part or other in prosecuting the war, and that everyone's efforts will be concentrated on carrying this war through to the only possible conclusion, no matter what may be the cost.

The Council have asked me to wish Godspeed to all members in this National work in the sure knowledge and appreciation that the Royal Aeronautical Society, throughout all its branches and grades, is playing a vital part in the conduct of the war.

At the outbreak of war, the Council was called upon to take immediate steps to consider the general policy of the Society and have arrived at the following conclusions.

The archives and valuable papers of the Society have been moved from No. 4, Hamilton Place to a suitable place of safety in the country where they will remain until the cessation of hostilities.

No. 4, Hamilton Place, the new headquarters of the Society, will be kept open. Captain Pritchard, with a skeleton staff, will remain at No. 4, Hamilton Place. Some of the rooms, including the Library, will be available for the use of members until further notice.

If members have any spare time whatsoever, it is the Council's earnest desire that they should endeavour to make as much use as possible of Hamilton Place whenever opportunity offers.

The lecture programme for the coming Session has been cancelled. It is realised that in wartime everybody is so busy that it is impossible to give sufficient importance to lectures, and that many subjects cannot be discussed with adequate freedom. The Wilbur Wright lecture, however, will take place next May.

If the war continues for a long period, it is hoped that we may be able to consider some curtailed form of lecture programme for the following session.

All the arrangements for the forthcoming International Congress at Stratford-on-Avon, which were making excellent progress, have had to be cancelled, and

the services of Colonel Edwards, who was doing good work on behalf of this conference, have had to be dispensed with for the duration of hostilities.

It is most important that the subscription list be kept up, and an endeavour made to increase the membership, and I hope that all members will make a point of paying their subscriptions promptly.

I cannot possibly conclude this letter without referring to the magnificent generosity of a large number of members of the Aircraft and Allied Industries, which has enabled the considerable sum of £109,202 4s. 0d. to be collected. This will ensure that the Society can be continued on a proper financial basis.

I am sure you will agree that the grateful thanks of all members of the Society are due to those who have made this possible, and I would like to record the Council's high appreciation of this generous help. A list of the subscriptions towards the funds of the Society will be found in the current issue of the Journal.

It is hoped that it will be possible to make another statement in regard to the activities of the Society early next year.

With all good wishes,

Yours truly,

A. H. R. FEDDEN,

President.

DONATIONS.

	£	s.	d.
Aluminium Union, Limited	250	0	0
Anglo-Swiss Aluminium Company, Limited; Aluminium-Industrie A.G., of Neuhausen, Switzerland	1,000	0	0
Anonymous	1,001	0	0
Anonymous	105	0	0
James Archdale and Company, Limited	403	17	0
Artex (1931), Limited	10	10	0
Asiatic Petroleum Company, Limited	5,000	0	0
Associated British Machine Tool Makers, Limited ...	100	0	0
Associated Ethyl Company, Limited	210	0	0
Baird and Tatlock (London), Limited	10	10	0
Mr. W. G. Bedford	20	0	0
Birmid Industries, Limited	2,100	0	0
Mr. R. Blackburn, F.R.Ae.S., M.I.Ae.E.	5,000	0	0
Blackwell's Metallurgical Works, Limited	105	0	0
Thomas Bolton and Sons, Limited	367	10	0
James Booth and Company (1915), Limited	1,500	0	0
Boulton Paul Aircraft, Limited	700	0	0
T. F. and J. H. Braime, Limited	50	0	0
Bristol Aeroplane Company, Limited	5,250	0	0
British Foundry Units, Limited	15	15	0
British Furnaces, Limited	105	0	0
British Thomson-Houston Company, Limited	500	0	0
British Wire Products, Limited	105	0	0
Bruntons (Musselburgh), Limited	10	10	0
Cellon, Limited	769	5	0
Charles Churchill and Company, Limited	250	0	0
Churchill Machine Tool Company, Limited	403	17	0
Clyde Alloy Steel Company, Limited	350	0	0
Coventry Gauge and Tool Company, Limited	500	0	0
James Day Sheet Metal Workers, Limited	105	0	0
De Havilland Aircraft Company, Limited	1,000	0	0
Mr. Leo d'Erlanger (Companion)	100	0	0
Mr. W. C. Devereux, F.R.Ae.S., M.I.Ae.E.	3,000	0	0
W. B. Dick and Company, Limited	10	10	0
Distillers Company, Limited	52	10	0
Dunlop Rubber Company, Limited	1,540	0	0
Dzus Fastener (Europe), Limited	5	5	0
E.N.V. Engineering Company, Limited	250	0	0
Carried forward	**32,255**	**19**	**0**

	£	s.	d.
Brought forward	32,255	19	0
Mr. C. R. Fairey, M.B.E., F.R.Ae.S.	1,125	0	0
The Fairey Aviation Company, Limited	5,250	0	0
Mr. A. H. R. Fedden, M.B.E., D.Sc., F.R.Ae.S. ...	500	0	0
Thos. Firth and John Brown, Limited	1,538	10	0
Firth-Derihon Stampings, Limited	500	0	0
Firth-Vickers Stainless Steels, Limited	1,077	0	0
Foundry Services, Limited	210	0	0
Gibbons (Dudley), Limited	26	5	0
Mr. F. Handley Page, C.B.E., F.R.Ae.S., M.I.Ae.E. ...	10,003	0	0
Hawker Siddeley Aircraft Company, Limited	5,250	0	0
Thos. P. Headland, Limited	5	5	0
Heald Machine Company	1,000	0	0
Heenan and Froude, Limited	700	0	0
Alfred Herbert, Limited	350	0	0
High Duty Alloys, Limited	1,000	0	0
H. M. Hobson (Aircraft and Motor) Components, Limited	105	0	0
Hoffmann Manufacturing Company, Limited	700	0	0
Mr. J. W. Howlett	105	0	0
Hoyt Metal Company of Great Britain, Limited	105	0	0
F. A. Hughes and Company, Limited; Magnesium Elektron, Limited	2,100	0	0
Hughes-Johnson Stampings, Limited	1,102	10	0
Imperial Chemical Industries, Limited	1,000	0	0
Intava, Limited	1,500	0	0
Integra Company, Limited	50	0	0
International Alloys, Limited	500	0	0
Johnson and Phillips, Limited	200	0	0
Lord Kenilworth, C.B.E., F.R.Ae.S.	5,000	0	0
Arthur Lee and Sons, Limited	100	0	0
Lockheed Hydraulic Brake Company, Limited	525	0	0
Magnesium Castings and Products, Limited	500	0	0
B. and S. Massey, Limited	500	0	0
May and Baker, Limited	10	10	0
W. and E. Moore, Limited	10	10	0
Morgan Crucible Company, Limited	105	0	0
Herbert Morris, Limited	105	0	0
D. Napier and Son, Limited	1,000	0	0
Noble and Lund, Limited	50	0	0
Northern Aluminium Company, Limited	1,750	0	0
Mr. W. A. Oubridge, M.I.Mech.E., M.I.A.E.	500	0	0
Plessey Company, Limited	750	0	0
Ragosine Oil Company, Limited	10	10	0
Ransome and Marles Bearing Company, Limited ...	735	0	0
Carried forward	79,909	19	0

	£	s.	d.
Brought forward	79,909	19	0
Rolls-Royce, Limited	5,250	0	0
Rotax, Limited	250	0	0
Rubery, Owen and Company, Limited	350	0	0
Saunders-Roe, Limited	262	10	0
Shell-Mex and B.P., Limited	1,500	0	0
Mr. H. O. Short, F.R.Ae.S.	10,000	0	0
Slough Estates, Limited	105	0	0
S. Smith and Sons (Motor Accessories), Limited; K.L.G. Sparking Plugs, Limited; Henry Hughes and Son, Limited	500	0	0
Smith's Stamping Works (Coventry), Limited	500	0	0
Société Genévoise d'Instruments de Physique	500	0	0
George Spencer, Moulton and Company, Limited ...	21	0	0
Leo C. Steinle, Limited	500	0	0
George Turton, Platts and Company, Limited	500	0	0
United Steel Companies, Limited	1,000	0	0
Vickers-Armstrongs, Limited	5,250	0	0
Mr. M. H. Volk, F.R.Ae.S.	26	5	0
C. C. Wakefield and Company, Limited	1,500	0	0
H. W. Ward and Company, Limited	262	10	0
Robert Watson and Company (Constructional Engineers), Limited	105	9	0
Wellworthy Piston Rings, Limited	105	0	0
A. C. Wickman, Limited	700	0	0
Yorkshire Engineering Supplies, Limited	105	0	0
	£109,202	4	0

THE STABILISATION OF A THIN SHEET BY A CONTINUOUS SUPPORTING MEDIUM.

By G. S. Gough, C. F. Elam (Mrs. G. H. Tipper), N. A. de Bruyne.
Cambridge University Engineering Laboratory.
August, 1939.

Introduction.

The structural problems of metal aircraft design largely centre round the difficulty of making efficient compression members. This difficulty is accentuated when loads are small in relation to the size of the structure. For example, the diameter of an aeroplane fuselage cannot usually be less than the height of a man, which results in such small forces at the surface of the shell that the lightest practicable beam is quite disproportionate to its strength.

As a measure of load in relation to size, it is convenient to use a quantity that we suggest may be called the " structure loading." This quantity, due to H. Wagner (8), is simply the square root of the applied load divided by a characteristic dimension (such as the length) of the member. It is a fact of experience that as the " structure loading " decreases, the efficiency of a material, judged by the load carried per pound of material, also decreases, no matter how ingeniously we may corrugate the cross-section of the member in an endeavour to secure the greatest possible moment of inertia and the maximum resistance to local wrinkling.

At structure loadings less than about 3 lb.$^{\frac{1}{2}}$/in. even magnesium alloys become inefficient ; yet such structure loadings are quite common in aircraft and it is therefore of importance to investigate methods of strut stabilisation other than the use of a corrugated profile.

A method, apparently first suggested by William Fairbairn (2) when carrying out experiments for the design of the Menai and Conway tubular bridges, consists in stabilising a metal sheet by an adjacent layer of low density material such as wood. The same principle has been suggested by Th. von Kármán and P. Stock (5), and by C. Dornier (4), and it has been used successfully by the de Havilland Aircraft Co. Ltd. in their " Albatross " type of machine.

In the present paper an analysis is given of the stability of such composite structures followed by experimental tests of some of the relations derived.

Part I. Theory.

Previous Work.

The buckling of a strut which is supported laterally by an elastic medium has been studied by Timoshenko (7), Granholm (3), Reissner (6) and others. Timoshenko and Granholm assume that the supporting lateral pressure at a point is proportional to the deflection at that point only and is independent of the configuration in the neighbourhood, which implies that the supporting medium acts as a series of independent springs without ability to transmit shearing stress. In some applications this assumption is justifiable, but clearly not when the supporting medium is continuous. Granholm recognises the incorrectness of the assumption but justifies it on the score of simplicity. Reissner comments on the general applicability of Timoshenko's result and solves the problem of an infinitely continuous strut resting on a series of equally spaced rigid supports and restrained on one side by a two-dimensionally infinite medium of the same width as the strut.

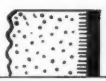
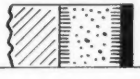
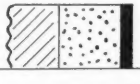
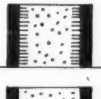
In so doing he makes use of a result given by Biot (1) on the deflection due to a sinusoidal distribution of pressure on one boundary of a semi-infinite elastic solid, the boundary being free from tangential stress.

In what follows, Biot's result has been extended to include various conditions of finite and infinite thickness of the supporting medium, both with and without tangential constraint between the surface of the medium and the compression member. On the other hand, no account is taken of an arbitrarily fixed spacing of the supports for which Reissner's solution makes provision; but in its stead the spacing is assumed to have one of those values for which the strength is at an absolute minimum. There is thus a considerable gain in simplicity and the results can be reduced to intelligible graphical form. As is explained below, the error involved can have next to no practical significance.

Cases Considered.

The various combinations of skin and supporting medium considered are summarised in Table I below.

Table I.

Description.	Diagrammatic Representation.	Case No.
Semi-infinite supporting medium. Complete adhesion between surfaces.		Ia
Semi-infinite supporting medium. No adhesion between surfaces.		Ib
Supporting medium of finite thickness with rigid back. Complete adhesion between surfaces.		IIa
Supporting medium of finite thickness with rigid back. No adhesion between surfaces.		IIb
Supporting medium of finite thickness with free back. Complete adhesion between surfaces.		IIIa
Supporting medium of finite thickness with free back. No adhesion between surfaces.		IIIb
Supporting medium of finite thickness with skin on both faces. Complete adhesion between surfaces.		IVa
Supporting medium of finite thickness with skin on both faces. No adhesion between surfaces.		IVb

Back Skin
Medium

Assumptions.

Besides the usual assumptions of elasticity and homogeneity in the skin and in the supporting medium, the solutions obtained require the fulfilment of certain conditions, whereas only an approximate fulfilment may, in fact, be possible.

(1) In all cases, it is assumed that the whole of the compressive load is taken by the skin alone. This will be very nearly true if, as in the experiments, Young's modulus for the skin is large in comparison with that for the medium; it is not difficult, if necessary, to make an approximate allowance for the load carried in direct compression by the supporting medium. This assumption becomes much less true after buckling of the skin has begun to take place, as its effective axial stiffness is then considerably reduced and a progressively increasing proportion of the load is transferred to the supporting medium.

(2) In all cases it is assumed that the medium can support the skin by transverse forces which can act both in tension and in compression. This presupposes either the existence of adhesion between the skin and medium or else that the supporting medium is held up against the skin by a clamping pressure.

(3) In cases I(a), II(a), III(a), IV(a) longitudinal forces are considered to be acting on the surface of the supporting medium and these must have some effect on the skin. But if the thickness of the skin and the amplitude of any deflection are small compared with the wavelength of the corrugations, the associated bending moments are negligible and to neglect the direct effects is equivalent to making the first assumption above.

(4) In cases I(a), II(a), III(a), IV(a) the adhesion has been taken to be complete in the longitudinal as well as in the transverse direction, which, on neglecting the strains in the skin, implies that there is no longitudinal movement of the surface of the medium.

(5) In cases I(b), II(b), III(b), IV(b) it has been supposed that there is complete longitudinal freedom and consequently no tangential stress on the surface of the supporting medium. This condition is purely hypothetical but is interesting in contrast with the above cases and as a link with Reissner's result.

General Method of Solution.

Although with a continuous supporting medium it is not justifiable to assume that the ratio of lateral pressure to the deflection is independent of the form of the deflection, for the particular conditions considered, in which the deflection and pressure have sinusoidal variation of the same wave length, it is possible to express the connection in the form:—

$$\text{pressure} = \text{coefficient} \times \text{deflection}$$

in which the coefficient is a function of the wave length, but independent of position.

In the solution therefore, this coefficient is determined and inserted in the differential equation which must be satisfied by the transverse deflection in a position of equilibrium. The solution of this equation justifies the assumption of sinusoidal distribution, provided the supports impose no disturbing conditions. The solution also gives a definite value of the thrust P which is able to maintain buckling of a given wave length λ. The particular value of the wave length which corresponds with the least value of P is that of the corrugations which may be expected to develop and the corresponding value of P is the required critical thrust.

In assuming that corrugations of this wave length can develop, it is necessary to suppose that neither the total length nor the terminal conditions impose any constraint. With freely hinged supports at a distance equal to an integral product of the half wave length, this is true. But, in fact, the experiments show that at most a few corrugations develop and it appears to be inconceivable that their wave length should be appreciably affected by supports which are separated from the buckled portion by a length of skin which is sensibly straight for several wavelengths. Providing the total is sufficient to include several complete waves, there

does not appear to be any reason to expect any important influence from variation in the total length or from the support conditions.

In all the cases considered in which the thickness of the medium is finite and the back face has no rigid support, it is necessary to consider the possibility that buckling on the full length may occur before the development of corrugations.

NOTATION.

P = thrust in skin.
P_c = critical thrust in skin.
p_c = stress in skin corresponding with critical thrust.
q = tensile stress between skin and medium.
q_m = maximum value of the above in sinusoidal variation.
b = breadth of skin and medium.
s = thickness of skin.
E_s, σ_s = Young's modulus and Poisson's ratio of material of skin.
B = flexural rigidity of skin, $= E_s b s^3/12$ narrow, $= E_s b s^3/\{12(1-\sigma_s^2)\}$ wide.
t = transverse thickness of supporting medium.
E_o, σ_o = Young's modulus and Poisson's ratio of material of supporting medium.
λ = wave length of the corrugations.
L = full length between hinged supports.
$\alpha = 2\pi/\lambda$.
$\beta = \alpha t = 2\pi t/\lambda$.
$K = (s/t)(E_s/E_o)^{\frac{1}{3}}$.
x, y = cartesian co-ordinates, x in direction of the axis of thrust and y normal to common surface of skin and medium.
u, v = displacements of material of medium in x and y directions.
v_o = value of v at the common surface of medium and skin.
V, $\widehat{xx}$, etc., as usual in the theory of elasticity.

I (*a*) SEMI-INFINITE MEDIUM. COMPLETE ADHESION.

The common surface of the skin and the supporting medium is taken to lie in the plane $y=0$, and the medium, of the same width as the section of the skin considered, is supposed to extend to infinity on that side of the surface for which

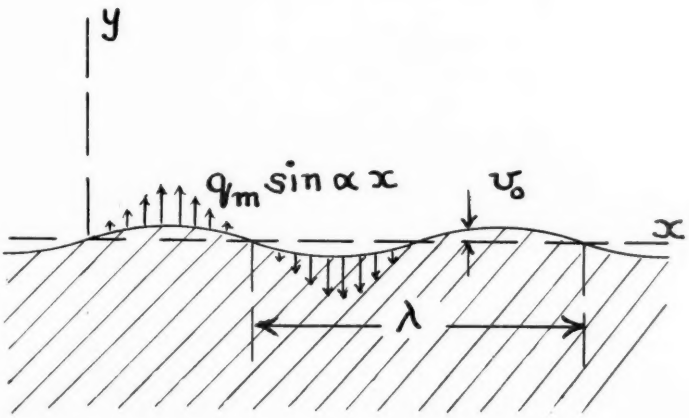


FIG. 1.

y is negative. The longitudinal displacement of the surface of the medium is constrained to be zero and a distribution of normal stress,

$$q = q_m \sin \alpha x,$$

is assumed to act between the skin and the medium, see Fig. 1.

This system of surface stress is self-balancing over an infinite length and the resultant distribution of stress throughout the medium must be expected to diminish to zero as y assumes large negative values.

These conditions are satisfied by the distribution given by the stress function :—

$$V = -(q_m/\alpha^2)\left[1 - \tfrac{1}{2}(1+\sigma_o)\,\alpha y\right] e^{\alpha y} \sin \alpha x.$$

It satisfies the equation

$$\partial^4 V/\partial x^4 + 2\,\partial^4 V/\partial x^2 \partial y^2 + \partial^4 V/\partial y^4 = 0;$$

it gives expressions for the stresses which contain the multiplier $e^{\alpha y}$ and so diminish as required; and at the surface it provides the required distribution of stress and satisfies the condition

$$E_o\,\partial u/\partial x = \widehat{xx} - \sigma_o \widehat{yy} = 0.$$

The surface displacement in this system is most readily calculated from the equation :—

$$E_o\,\partial^2 v/\partial x^2 = -(2+\sigma_o)\,(\partial^3 V/\partial x^2 \partial y) - \partial^3 V/\partial y^3$$

and is given by

$$v_o = (1+\sigma_o)\,(3-\sigma_o)\,q/2\,E_o\alpha.$$

For the skin, the differential equation which expresses the condition for the equilibrium of a slightly deflected position is

$$B d^4 v_o/dx^4 + p d^2 v_o/dx^2 + qb = 0$$

or on substituting for q

$$B d^4 v_o/dx^4 + p d^2 v_o/dx^2 + (2\,\alpha b E_o v_o)/(1+\sigma_o)\,(3-\sigma_o) = 0.$$

This equation shows that the assumed sinusoidal deflection of wave length $\lambda\ (=2\pi/\alpha)$ is a possible position of equilibrium if

$$P = B\alpha^2 + (2\,bE_o)/(1+\sigma_o)\,(3-\sigma_o).$$

Neglecting the possible effect of restrained secondary bending in a wide section of skin* and substituting for B, the above equation for the thrust can be reduced to that expressing the equilibrium stress

$$p = (\alpha^2 s^2/12)\,E_s + 2\,E_o/\{(1+\sigma_o)\,(3-\sigma_o)\,\alpha s\}\,\alpha.$$

This expression for the equilibrium stress becomes very large when αs is either very large or very small and has a single minimum value when

$$\alpha s = [12\,E_o/\{(1+\sigma_o)\,(3-\sigma_o)\,E_s\}]^{\frac{1}{2}}.$$

that is where

$$\lambda/s = 2\pi\,[\{(1+\sigma_o)\,(3-\sigma_o)\,E_s\}/12\,E_o]^{\frac{1}{2}}.$$

The corresponding critical value of the stress is given by

$$p_c/(E_o^2 E_s)^{\frac{1}{3}} = [3/\{2\,(1+\sigma_o)\,(3-\sigma_o)\}]^{\frac{2}{3}}.$$

I (b) Semi-infinite Medium. Longitudinal Freedom Between Surfaces.

In Biot's and Reissner's results the surface of the medium is taken to be free from shearing stress; the effect happens to be that of writing $\sigma_o = 1$ in the above expressions. Then

$$\lambda/s = 2\pi\,(E_s/3\,E_o)^{\frac{1}{3}}$$

and

$$p_c/(E_o^2/E_s)^{\frac{1}{3}} = (3/8)^{\frac{2}{3}}$$

I (a) and I (b) General Discussion and Graphical Representation of Results.

It is worthy of notice that it is possible to deduce from dimensional considerations that in both the above cases the effective stiffness of the support varies

* Even with the extreme value of $\sigma = 0.5$ the correction (though 33% in the rigidity) is only 11% in the critical stress. The correction can always be made by an adjustment of E_s.

inversely as the wave length. It is clear that geometrical similarity and therefore equality of strains exist when the maximum value of v_0 varies as λ. But the strain also varies as q_m/E_o, and as v_o for a given value of λ. Hence

$$v_o/\lambda \propto q_m/E_o$$

or

$$v_o \propto q_m/\alpha E_o.$$

The results obtained above for cases I (a) and I (b) are shown graphically in Fig. 2, which gives the values of

$$p_c/(E_o^2 E_s)^{\frac{1}{3}}$$

and of

$$(\lambda/s)\,(E_o/E_s)^{\frac{1}{3}}$$

plotted against the values of σ_0 between 0.25 and 0.5 for case I (a). The constant values of the same quantities corresponding to case I (b) are also indicated.

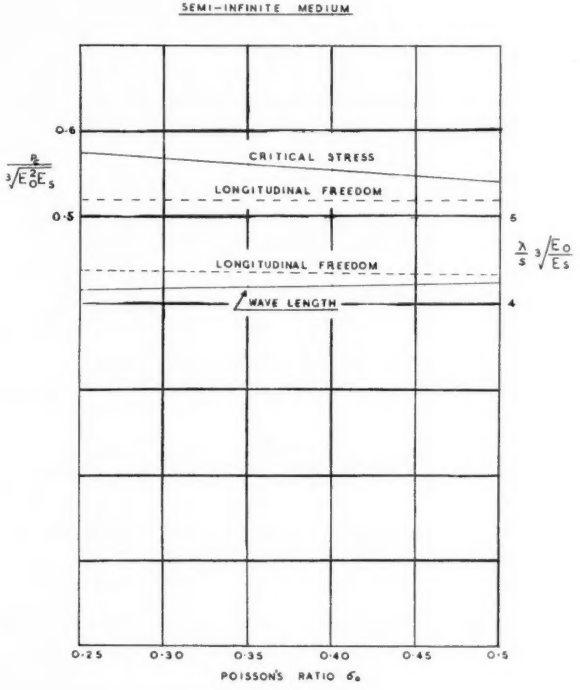


FIG. 2.

It will be seen that the effect of variation in Poisson's ratio or of the longitudinal constraint is not large. Undoubtedly these conditions are closely associated with the amount of support given by shearing deformations and with infinite thickness of support this is small.

II (a) MEDIUM OF FINITE THICKNESS WITH RIGID BACK. COMPLETE ADHESION. The skin is now taken to be supported on one side* by a layer of supporting

* When the skin is supported on both sides the total lateral force associated with a given deflection is twice what would be given by a support on one side only and equal to that given by a medium on one side but having a Young's modulus twice as large. Hence for two-sided support $2E_o$ should be substituted for E_o.

medium of thickness t, the back of which is rigidly supported. Adhesion between the medium and the skin and between the medium and the backing is assumed to be complete so that longitudinal movement of either surface of the medium is prevented.

With these conditions the rigidity of the support provided by the medium is given by*

$$q/v_o = \{ 2 E_o a [(3-\sigma_o) \sinh \beta \cosh \beta + (1+\sigma_o) \beta] \} / \{ (1+\sigma_o)(3-\sigma_o)^2 \sinh^2 \beta - (1+\sigma_o)^3 \beta^2 \},$$

where

$$\beta = at = 2\pi t/\lambda.$$

With this rigidity the stress, under which corrugations of wave length λ can be maintained, is to be found from the equation

$$p/(E_o^2 E_s)^{\frac{1}{3}} = \beta^2 K^2/12 + \{ 2 [(3-\sigma_o) \sinh \beta \cosh \beta + (1+\sigma_o) \beta] \} / \{ \beta K [(1+\sigma_o)(3-\sigma_o)^2 \sinh^2 \beta - (1+\sigma_o)^2 \beta^2] \}$$

in which K is equal to $(s/t)(E_s/E_o)^{\frac{1}{3}}$ and so is a measure of the relative flexural rigidities of the skin and the layer of medium.

For any particular value of K the stress given by this equation is very large when β is either very large or very small, but it falls to an intermediate minimum as shown for a particular case in Fig. 3.

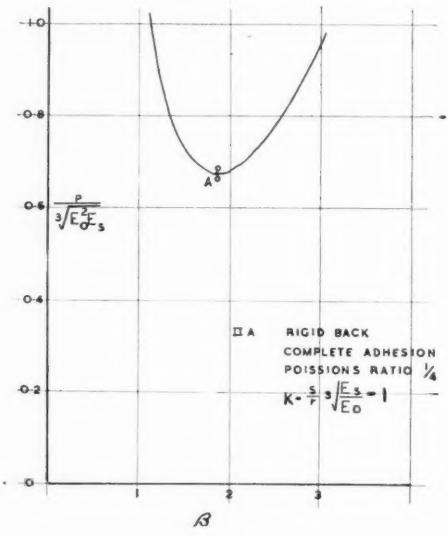


FIG. 3.

The minimum value of p (corresponding to point A in the figure) is the critical stress under which the skin may be expected to develop corrugations, at least when there is no end-effect; and the corresponding value of β gives the wave length of the corrugations in terms of the thickness of the medium.

In order to calculate this minimum the expression for $p/(E_o^2 E_s)^{\frac{1}{3}}$ is differentiated with respect to β and the resulting equation reduced to the form $K^3 = f(\beta)$ which is at once soluble if it be regarded as determining K for a given value of β. Even so, the calculation is cumbersome and mainly arithmetical, so that no

* The corresponding stress function is given in Appendix I.

object would be achieved by reproducing even the algebraical stages. The results are, however, easily represented graphically. For the particular cases $\sigma = \frac{1}{4}$ and $\frac{1}{2}$ they are set out in Figs. 4 and 5 respectively.

In each figure the abscissa is the value of K, while the ordinates of the upper curve give the critical stress in terms of the quantity $(E_0^2 E_s)^{\frac{1}{3}}$ and the ordinates of the lower curve give the ratio of the wave length to the thickness of the medium. Thus all variables are strictly non-dimensional and it is not necessary to specify units.

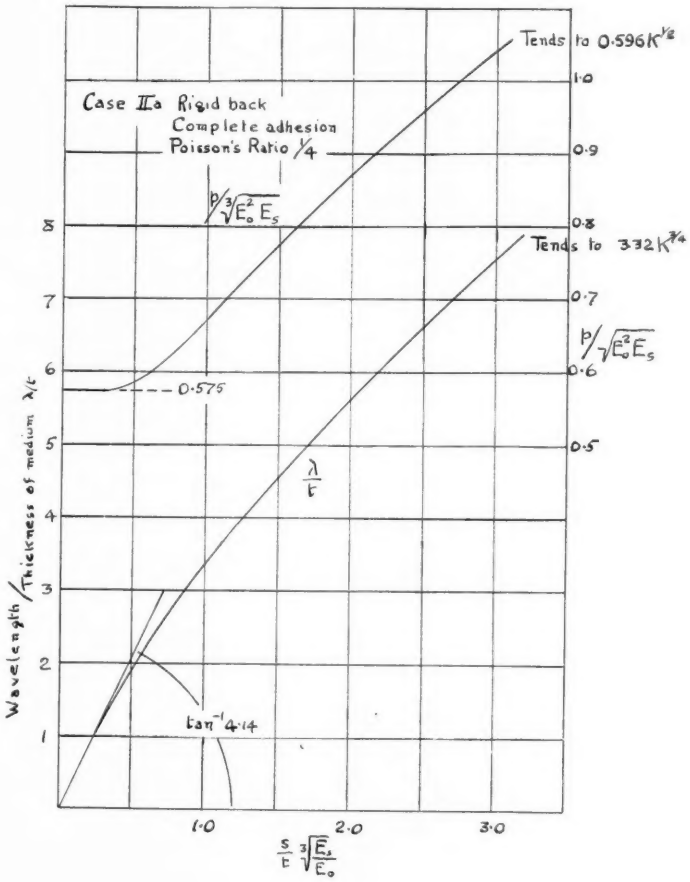


FIG. 4.

At the left-hand end of each diagram, for values of K less than about 0·3, there is no appreciable difference between the values given by these curves and those shown for the semi-infinite medium in Fig. 2. The value of K corresponds to an s/t ratio from 1/150 to 1/70 when the materials are steel and the extreme varieties of onazote used in the experiments. For greater values of K (*i.e.*, less thickness of medium) the rigid back makes itself apparent, the critical stress rises and the value of λ decreases, as is shown by the falling of the λ/t

curve below the straight line tangent at the origin. In comparing Figs. 4 and 5 it will be seen that the medium with a Poisson's ratio of $\frac{1}{4}$ gives the greater support for small values of K, but that the position is reversed when K is greater than about 1. The explanation appears to be as follows. As will be shown in the next section, the results are independent of Poisson's ratio when there is

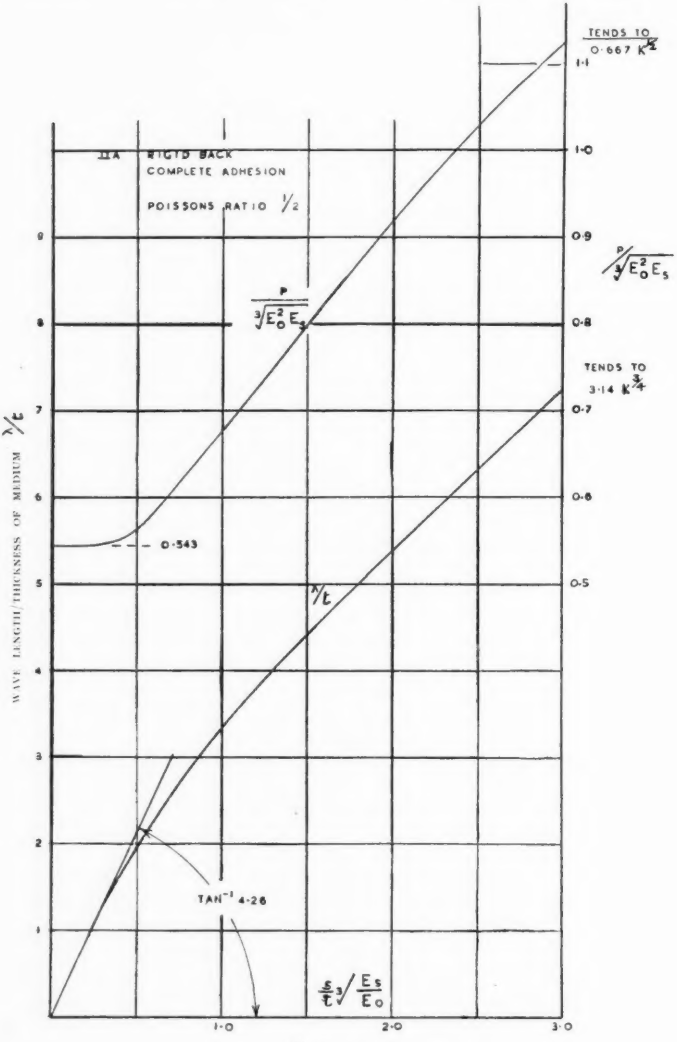


FIG. 5.

longitudinal freedom of the surfaces, so that the effect of Poisson's ratio may be looked for in the forces of adhesion necessary to prevent longitudinal surface movements. Now it may be shown that the amount of free movement tends to be independent of Poisson's ratio when K is small and proportional to σ_0 when K is large; while the shearing stresses involved in cancelling this motion must

depend to a large degree on the modulus of rigidity, that is upon $1/(1+\sigma_0)$ when Young's modulus is supposed constant. Assuming for the sake of argument that the stiffening effect is measured by the product of the free movement and the modulus of rigidity, it should vary as $1/(1+\sigma_0)$ when K is small and $\sigma_0/(1+\sigma_0)$ when K is large. These make the smaller value of σ_0 to be more effective when K is small and the larger value when K is large, which is in fact true.

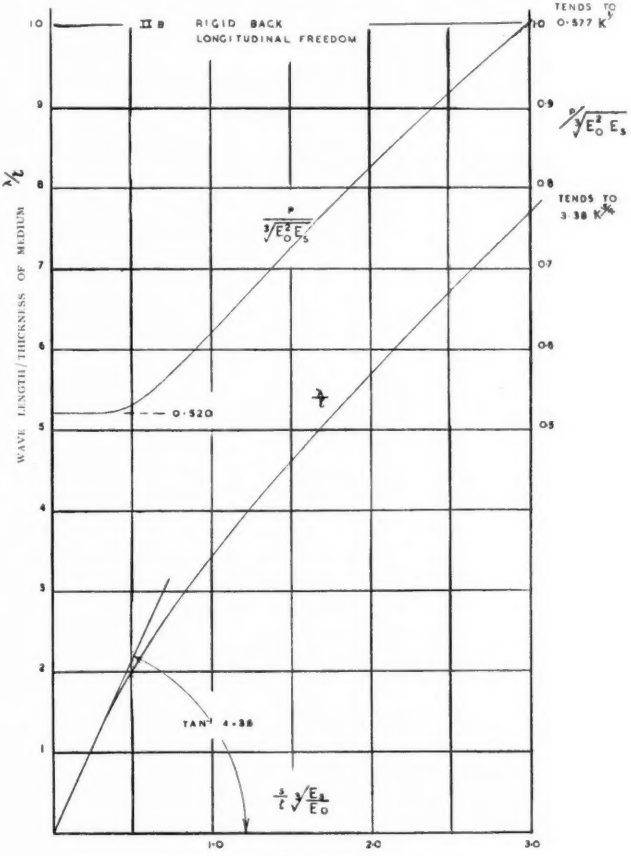


FIG. 6.

II (*b*) MEDIUM OF FINITE THICKNESS WITH RIGID BACK. LONGITUDINAL FREEDOM BETWEEN SURFACES.

In the absence of shearing stress on either surface of the medium, the equation for the equilibrium stress no longer involves Poisson's ratio and is

$$p/(E_0^2E_s)^{\frac{1}{3}}=\beta^2K^2/12+(\sinh\beta\cosh\beta+\beta)/(2K\beta\sinh^2\beta).$$

The general form of the relationship given by this equation is very similar to that applicable when there is adhesion, and Fig. 3 may be regarded as typical of the $p/(E_0^2E_s)^{\frac{1}{3}}-\beta$ curve for a constant value of K. The results are set out in Fig. 6 which is entirely comparable with Figs. 4 and 5 and should need no further explanation. The critical stress is appreciably lower, as is to be expected, and compared with Fig. 5 ($\sigma_0=\frac{1}{2}$) the wave length is greater. On the other

hand, the wave length given by Figs. 4 and 6 are very nearly identical, which may seem curious, but it should be remembered that the critical wave length depends not upon the absolute value of the effective rigidity of the support but upon the relation between this and the wave length.

III (*a*) Medium of Finite Thickness with Free Back. Complete Adhesion.

The conditions now considered are those of a skin supported on one side* by a uniform thickness of medium, the one face of which has complete adhesion to the skin and the back of which is unsupported. The corresponding equation for the stress to maintain corrugations is

$$p/(E_0^2E_s)^{\frac{1}{3}} = \beta^2K^2/12 + \{ 2(\sinh\beta\cosh\beta - \beta) \} / \{ \beta K [(3-\sigma_0)(1+\sigma_0)\sinh^2\beta + (1+\sigma_0)^2\beta^2 + 4] \}.$$

This gives a connection between $p/(E_0^2E_s)^{\frac{1}{3}}$, K and β which differs very considerably from that relating to the rigid back. When K is greater than a critical value of about 0.4, there is no possibility of corrugation, as $p/(E_0^2E_s)^{\frac{1}{3}}$ increases continuously from zero as β increases and there is no minimum, as is shown by the curve for $K=\frac{1}{2}$ in Fig. 7. Under this condition, the skin will always fail by buckling over its whole length in a manner which may be called "quasi-

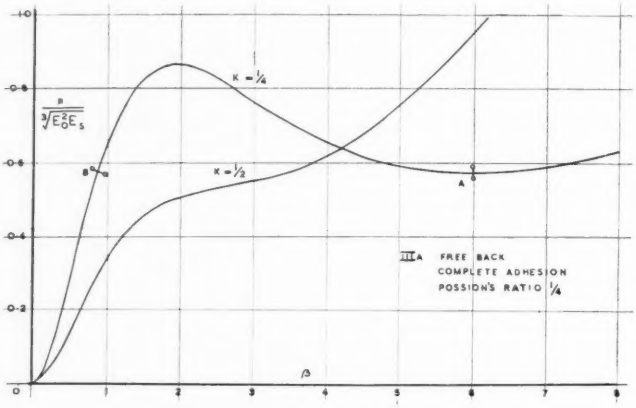


Fig. 7.

Euler." The limiting stress is given by the above equation on substituting the appropriate value of K and taking for β the value $\pi t/L$ where L is the full distance between hinged supports.†

Where K is less than the critical value, $p/(E_0^2E_s)^{\frac{1}{3}}$ increases from zero as before, but not continuously, as it now passes through maximum and minimum values. This is shown in Fig. 7 by the curve for $K=\frac{1}{4}$. The minimum point A in the figure gives the critical stress under which corrugation can develop. But there is now an additional consideration arising from the existence of a reach of the curve between the origin and the point B for which the ordinates are less than that of point A. In this reach, the lowest possible value of β gives the lowest stress under which a deflected position can be an equilibrium position, and therefore the stress under which buckling is to be expected. The failure would be quasi-Euler and would have a wave length of $2L$ and correspond to a value of β of $\pi t/L$. It becomes clear, therefore, that if the value of L can be restricted to that corresponding to point B, the quasi-Euler failure will not occur and the full critical stress for corrugation can be realised.

* See footnote (1) p. (Case IIa).
† See Appendix II.

The conditions relating to the development of corrugation are set out graphically in Figs. 8 and 9 for values of Poisson's ratio of $\frac{1}{4}$ and $\frac{1}{2}$ respectively. Each figure shows three curves with a common abscissa of K; those for the values of $p/(E_0^2E_s)^{\frac{1}{3}}$ and λ/t for the critical stress and wave length of true corrugation (point A of Fig. 7) and one curve for the value of L/t at point B. The last curve fixes an upper limit to L/t above which the other curves cease to be applicable. The greatest value of K for which a minimum occurs, and corrugation is possible, is that at the right-hand end of the diagram: 0.435 for $\sigma_0=\frac{1}{4}$

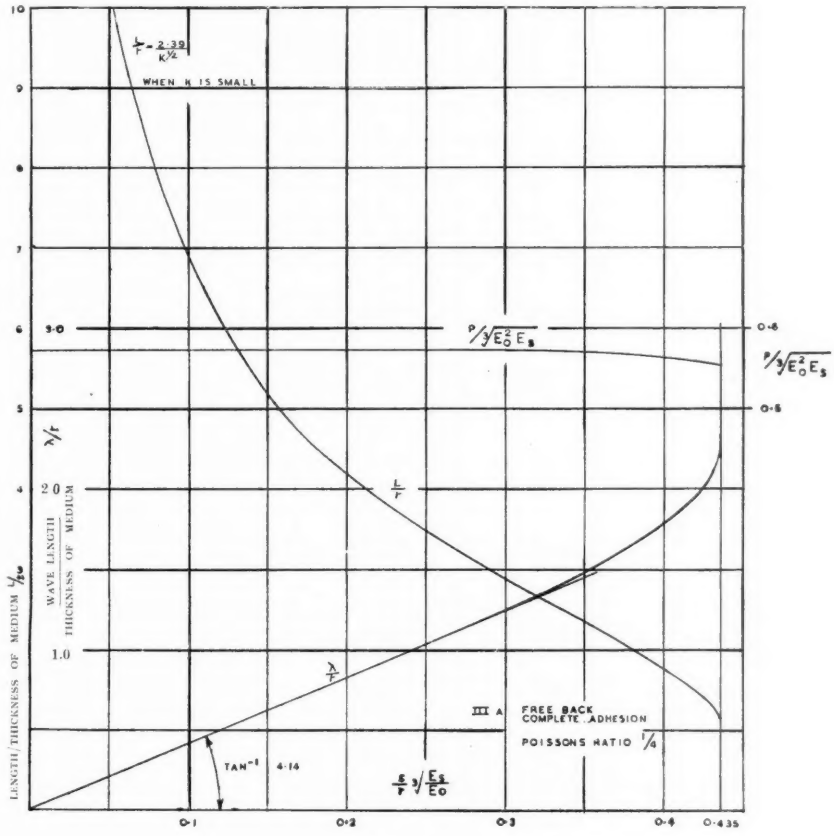


FIG. 8.

and 0.408 for $\sigma_0=\frac{1}{2}$. Up to values of K of about 0.35 there is only an insignificant departure from the straight lines giving the critical stress and wave length of the semi-infinite medium; but the L/t curve sets a severe practical limit to the application of this form of stabilisation, as for a great part of the possible range the spacing of the supports would have to be inconveniently close. For example, in order to develop the critical stress corresponding to a value of 0.2 (half the full range) the supports would have to be as close as four times the thickness of the packing if hinged or eight times if effective directional constraint can be relied upon.

At the right-hand end of Figs. 8 and 9 the total length is limited by the L/t curve to such a small number of half-waves (four at the intersection of the L/t and λ/t curves) that it might seem that the end effect would be considerable when $2L/\lambda$ was not an integer. Fig. 7, however, shows by its flat minimum that for these larger values of K the wave length can adjust itself to an integral value without appreciable alteration to the critical stress.

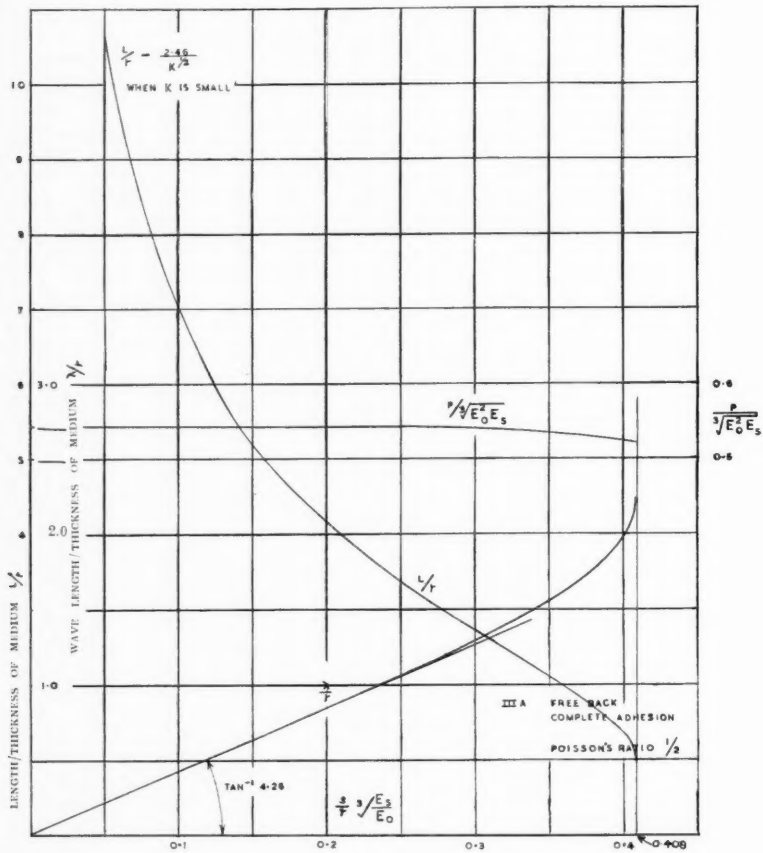


FIG. 9.

III (*b*) MEDIUM OF FINITE THICKNESS WITH FREE BACK. LONGITUDINAL FREEDOM.

Although it is difficult to imagine the practical possibility of adhesion between the skin and the medium which is capable of being complete as regards transverse deflections and non-existent in the longitudinal direction, this state is worthy of inclusion on account of academic interest and because it provides some clue of the behaviour to be expected when longitudinal adhesion is not completely effective.

The appropriate equation is:—

$$p/(E_0^2E_s)^{\frac{1}{3}} = \beta^2K^2/12 + \{ \sinh^2\beta - \beta^2 \} / \{ 2K\beta(\sinh\beta\cosh\beta + \beta) \},$$

which gives curves generally very similar to those applicable to case III (*a*). The $p_c/(E_0^2E_s)^{\frac{1}{3}}$, λ/t and L/t curves are shown in Fig. 10. The maximum value

of K has fallen to 0.357, but the great difference is in the L/t curve which lies far below the corresponding curves of Figs. 8 and 9. In order to make use of the critical stress when $K=0.2$ the value of L/t must now be rather less than $2\frac{1}{2}$ instead of the previous value of 4. In this respect longitudinal adhesion is very important.

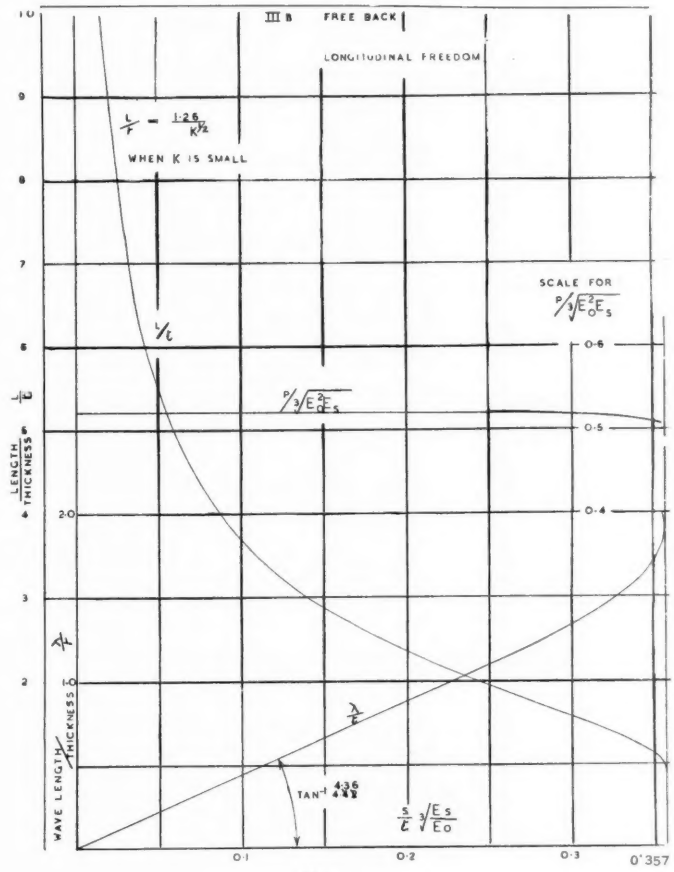


FIG. 10.

IV (*a*) MEDIUM OF FINITE THICKNESS WITH STRESSED SKIN ON BOTH FACES.

In this case a single layer of medium is considered to be supporting a stressed skin on each face with complete surface adhesion, a condition which represents the most probable practical application of this method of stabilising a thin skin.

It is clear that the amount of support given to either skin is to some degree dependent on the stress carried by the other and that a complete solution is for that reason extremely involved; and so, to avoid unnecessary complications, attention is confined to equal stresses in the two skins. With this condition the manner of failure may be taken to be that shown in Fig. 11. In this, each skin only helps the other by the longitudinal constraint, as the transverse displacements of the medium associated with each skin deflection are in the same sense; the longitudinal displacements, on the other hand, tend to cancel. When

the stresses are not equal, collapse is to be expected in a rather similar form, but with the greater stress at a rather higher value.

With equal skin stresses and with failure in the manner of Fig. 11 the stress equation is:—

$$p/(E_o^2 E_s)^{\frac{1}{3}} = \beta^2 K^2/12 + \{2(\cosh\beta - 1)\}/\{\beta K[(1+\sigma_o)(3-\sigma_o)\sinh\beta + (1+\sigma_o)^2\beta]\},$$

a relationship which differs in general form from any of those previously considered. When K is less than $\{(1-\sigma_o)/8(1+\sigma_o)\}^{\frac{1}{3}}$ the curve connecting $p/(E_o^2 E_s)^{\frac{1}{3}}$ and β is generally similar to that shown for $K=\frac{1}{4}$ in Fig. 12. There is a true minimum at A which gives the critical stress under which corrugation may be expected to develop and as no part of the curve lies below this minimum

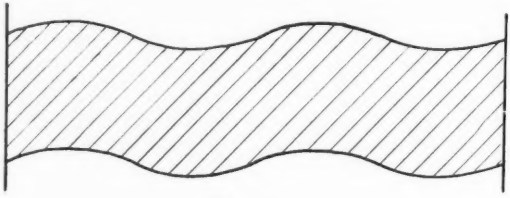


FIG. 11.

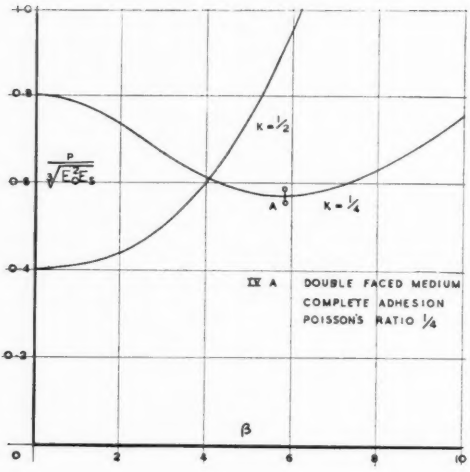


FIG. 12.

there is no possibility of quasi-Euler buckling over the whole length between supports. Numerical results for this condition are given graphically in Figs. 13 and 14 for values of Poisson's ratio of $\frac{1}{4}$ and $\frac{1}{2}$ respectively. It will be seen in these diagrams that the limiting values of K are 0.422 and 0.347 respectively, and that below these limits there is little falling below the critical stress with the semi-infinite medium. The wave length also is little affected over some three quarters of the range, but in the remaining portion it increases rapidly, changing the corrugated failure to the quasi-Euler.

When the value of K exceeds the limit stated above, the variation of $p/(E_o^2 E_s)^{\frac{1}{3}}$ with β becomes of the form shown for $K=\frac{1}{2}$ in Fig. 12. A mathematical minimum occurs where β is zero at a value of the stress which is finite. Since the corre-

sponding spacing of the supports is infinite it is perhaps surprising that the critical stress is not zero. This stress, however, arises from the resistance of the composite member to shearing deformation and while it may not represent a practical solution, it appears to be a true limit to the solution under non-limiting conditions.

The value of the critical stress is obtainable by substituting appropriate figures for K and β $(\pi t/L)$ in the above equation. When, however, t/L does not exceed about 1/10, an approximate method can be used in conjunction with Figs. 15 and 16. For these small values of t/L the critical stress is sufficiently nearly of the parabolic form $m+n\,(t^2/L^2)$, where m and n are functions of K, so that when the values for $t/L=0$ and 1/10 are known, intermediates can be interpolated proportionally to t^2/L^2. These values are given in Figs. 15 and 16 for Poisson's ratio equal to $\frac{1}{4}$ and $\frac{1}{2}$ respectively and the Figs. 15 and 16 also repeat the information of Figs. 13 and 14 to a smaller scale.

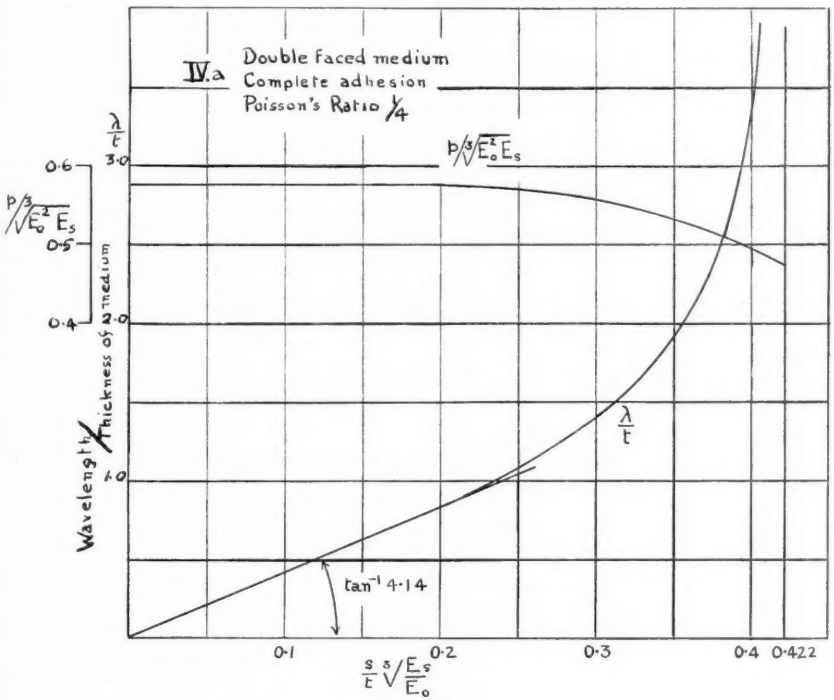


FIG. 13.

IV (*b*) MEDIUM OF FINITE THICKNESS WITH STRESSED SKIN ON BOTH FACES. LONGITUDINAL FREEDOM.

In order to show the difference made by the adhesion between the medium and the skin, this last condition is considered in which the medium is bounded by two skins but is subjected to no longitudinal constraint. The stress equation is then:—

$$p/(E_0^2E_s)^{\frac{1}{3}}=\beta^2K^2/12+\{\sinh\beta-\beta\}/\{2K\beta(\cosh\beta+1)\}.$$

This is very similar in its effect to those of section III (*a*) and (*b*), and Fig. 7 may be taken as typical. In fact, the present conditions are equivalent to a single layer of medium thickness $t/2$ supporting a skin on one face, there being

no longitudinal freedom on this face, and transverse freedom with longitudinal constraint on the back. So that the conditions of cases III (*a*) and (*b*) and case IV (*b*) differ only in the longitudinal constraint; in case III (*b*) there is none, in case III (*a*) it exists in the face only and in the present section on the back only.

The results of this form of support are set out in Fig. 17 which is, for the above reason, very similar and quite comparable with Figs. 8-10, with the exception of the scale changes due to $t/2$ replacing t. Comparison with Figs. 13 and 14 shows a reduction in the range of possible corrugation, from $K = 0\text{-}0.422$ in Fig. 13, 0-0.347 in Fig. 14, to 0-0.245 in Fig. 17; but as in Section III, the

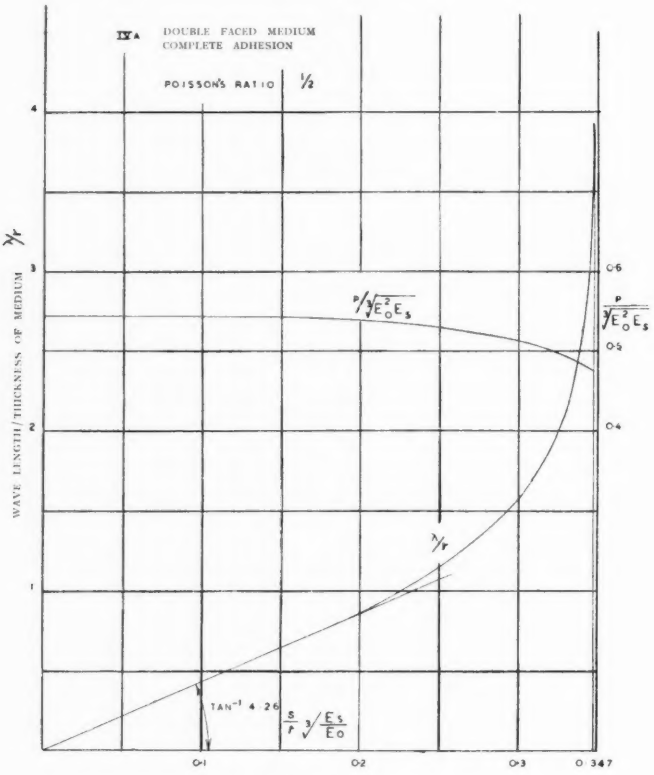


FIG. 14.

important conclusion is that a loss of surface adhesion can only be compensated by a drastic restriction of the L/t ratio. Moreover, when K is above the limit of corrugation and tends to zero there is now no finite strength available.

PART II.

EXPERIMENTAL WORK.

Of the various combinations of skin and supporting medium considered in Part I, Cases II (*a*), II (*b*), III (*a*) and IV (*a*) are capable of experimental investigation. Tests have been made, reproducing the theoretical conditions as nearly as possible, for three of these, namely, II (*b*), III (*a*) and IV (*a*).

GENERAL DESCRIPTION OF TESTS. SKIN MATERIAL.

Most of the experiments were done with spring steel which had a tensile strength of from 75-100 tons/in.^{2}, with no measurable elongation. Tests were also made with duralumin, elektron and birch ply. Different widths and thickness of strip were used to suit the requirements of each method of testing. The materials had the following properties :—

Material.	Young's Modulus E. lb./in.^{2}	Yield Point (in tension) lb./in.^{2}
Spring steel ...	30×10^6	156,500-224,000 (approx.)
Duralumin ...	10.8×10^6	34,450
Elektron ...	6.1×10^6	25,650
Birch ply ...	1.5×10^6	—

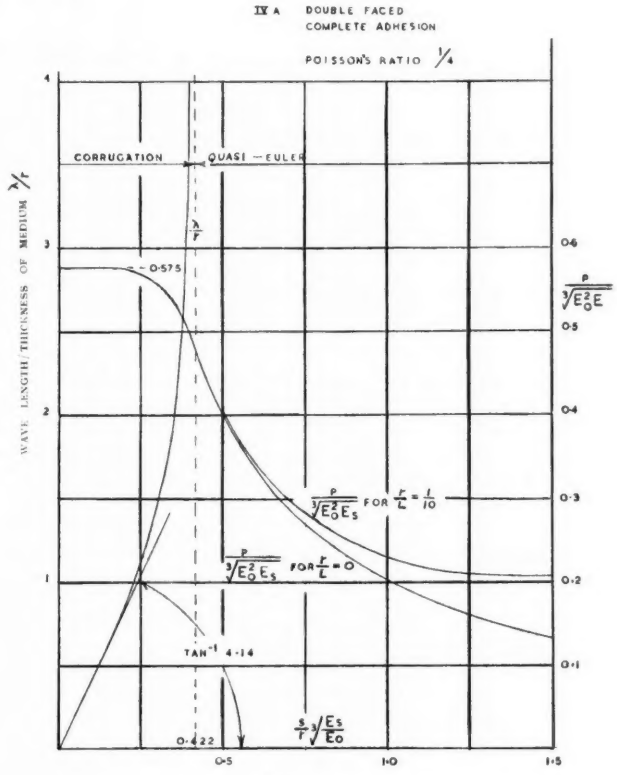


FIG. 15.

SUPPORTING MEDIUM.

Theoretical analysis assumes that the direct compression taken by the supporting medium is negligibly small in comparison with that taken by the skin. This condition was satisfied by the use of an expanded ebonite ("Onazote") which is obtainable in a range of specific gravity (ρ) of from 0.04 to 0.15, with an approximately linear variation in elastic modulus (E_o) according to the relation

$$E_o = 27{,}100\ \rho \text{ lb./ins.}^2,$$

The value of E_o for the material of highest density ($\rho=0.135$) 3,390 lb./in.^{2}. For spring steel, therefore, a thickness of onazote fifty times that of the skin material causes an error of less than 0.5 per cent.

Onazote has a cellular structure in which each air bubble is completely separated from its neighbours. The diameter of these bubbles, which is never greater than 1.5 mms. in the lowest density material, is very small compared with the wave length of the corrugations developed in the skin at failure. The material is not entirely homogeneous and tends to exhibit directional properties. Its elastic properties are also altered by cutting, crushing or squeezing. The strips required were cut in the same direction, all skin was removed as this

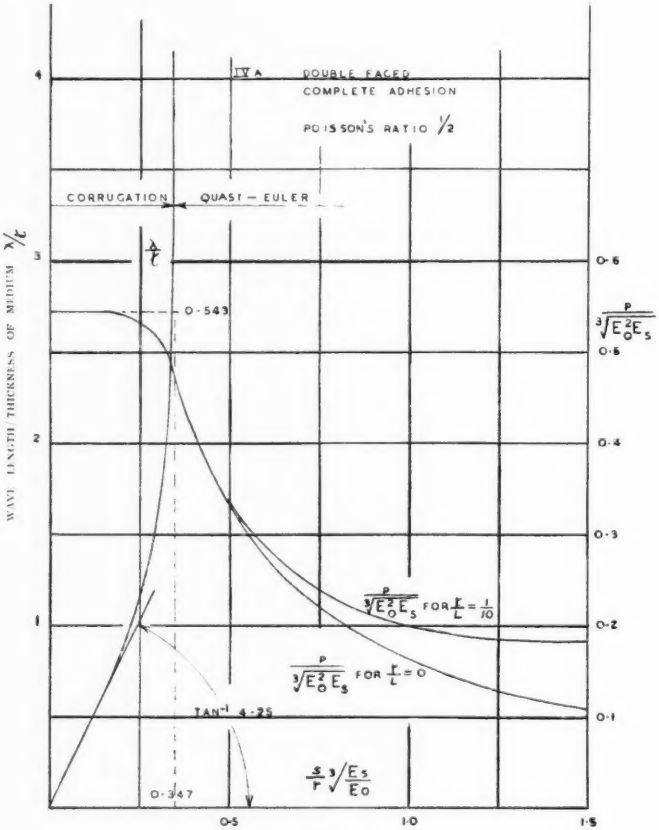


FIG. 16.

tended to be harder and more dense than the bulk of the material, and a frequent check was made on the value of E_o and the density, density determinations being made for each series of strips. Nevertheless, errors due to one or more of the causes enumerated must be taken into account.

In cases II (*a*), III (*a*) and IV (*a*) a knowledge of the value of Poisson's ratio, σ_o, is required. Measurements of the anticlastic curvature developed in a beam bent to a circular shape gave a mean value of $\sigma_o=0.3$. In order to obtain adhesion between the supporting medium and the skin a rubber latex

cement, sold under the trade name of " Semtex," was used. This contains a vulcanising agent which hardens at room temperature, but the process is accelerated by heating at 70°C. and this temperature was found to have no effect on the properties of the onazote.

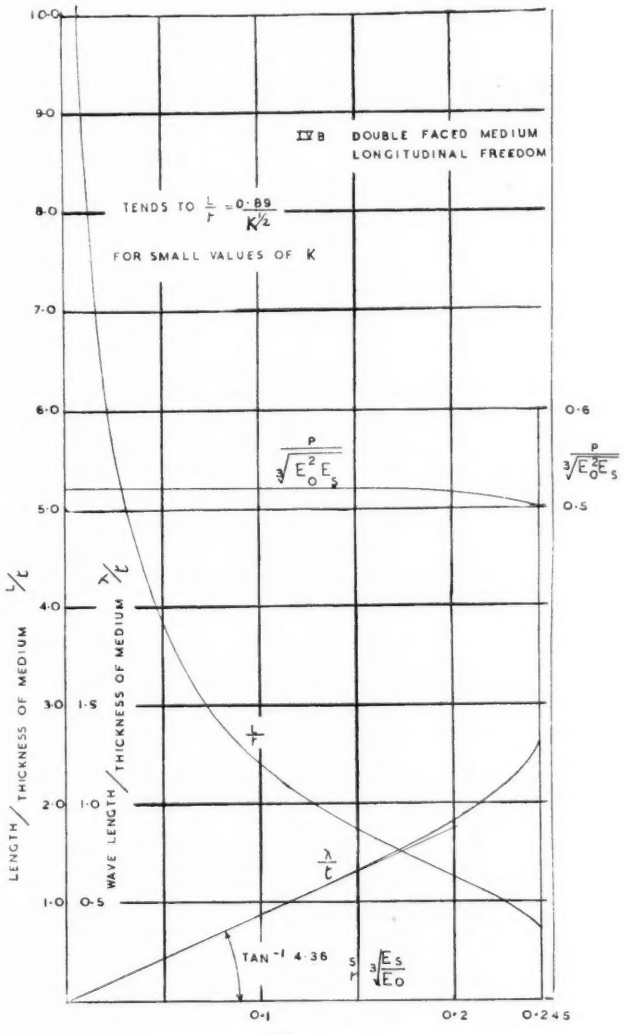


FIG. 17.

TESTING MACHINE.

The load was applied by means of a small Amsler machine designed for compression tests, adjusted to give a full-scale reading of either 500 lbs. or 5,000 lbs., and calibrated before use with weights.

Special holders for the test pieces were required and guides to reduce a tendency to instability in the case of the longer test pieces when the load was applied.

Failure was indicated by the sudden fall back in the load indicating pointer. A check on this method was made in several cases by using a dial gauge to measure the strain and subsequently plotting the load-strain curve. The relationship was linear up to the failing load, when a sudden change in direction occurred.

TEST PIECES.

By far the greatest difficulty encountered was premature failure at the ends of the strip. This was of two kinds. First, the extreme edge of the strip crumpled under the pressure of the applied load. This was obviated by reinforcing it on both sides by additional strip and holding the ends in clamps. The second type of failure occurred between the clamp and the supporting onazote or, if the reinforcing strips were carried far enough into the onazote, at the point where they ended. This difficulty was never overcome entirely, although the use of shaped test pieces in the case of II (*b*), and Semtex cement to stick strip, onazote and holders together in III (*b*) and IV (*a*), reduced its occurrence to some extent. The majority of the low results can be attributed to this cause.

Further details of test pieces and holders will be given in descriptions of separate cases. Certain general considerations apply to all the tests with regard to the relationship between thickness of strip (s), thickness of onazote (t), Young's modulus of strip (E_s) and onazote (E_o) and the total length of test piece. In the first place, the test pieces must be longer than a complete wave length, but, in case III (*a*), not so long that a "quasi-Euler" failure is likely to occur. Short test lengths gave the most satisfactory results. To ensure failure by corrugations, it is necessary according to the theory, that $(s/t)(E_s/E_o)^{\frac{1}{3}}$ or $(s/t)(E_s/2\,E_o)^{\frac{1}{3}}$ should be less than a certain minimum value, which may be obtained from the graphs, otherwise a quasi-Euler type of failure is again obtained. The thickness of strip is therefore limited by the thickness of onazote which is available or which it is practicable to use. It is also limited by the Young's modulus of the onazote; the softer the onazote, the thinner the strip has to be. The failing load is then very small and the error in measuring it proportionally increased.

In order to test the theory fully, experiments were made with various combinations of strip and onazote thickness, although some of these fell outside the range where corrugations are to be expected. Other conditions of testing investigated were:—(1) Variation of width of strip; (2) variation of width of onazote; (3) effect of lateral pressure, in case II (*b*); (4) different methods of supporting the ends.

The results summarised in the tables below represent only a small proportion of tests actually made. Results which might be considered doubtful, from any cause, have been omitted.

As case II (*b*) presented fewer experimental difficulties and a wider range of skin thickness and onazote density could be tried, this method has been investigated most fully. The test conditions, however, lie between II (*a*) and II (*b*) owing to friction between skin and medium, and approach II (*a*) with increase of lateral pressure.

CASE II (*b*). SUPPORTING MEDIUM OF FINITE THICKNESS WITH RIGID BACK. NO ADHESION BETWEEN SURFACES. EXPERIMENTS WITH SPRING STEEL.

To ensure failure at the required point, shaped test pieces were prepared of the following dimensions: total length 5 in.; parallel portion 2.25 ins. long, 0.25 ins. and 0.5 ins. wide. The ends were 1.0 ins. by 0.5 ins. or 1.0 ins., according to the width of the parallel portion. Four thicknesses of strip were used, *i.e.*, 0.005, 0.010, 0.015 and 0.020 ins., and of these the two intermediate thicknesses gave the most satisfactory and reliable results.

The onazote used may be divided roughly into two grades having densities of 0.04-0.06 and 0.10-0.13 respectively. It was found impracticable to cut the

onazote to fit the test pieces and difficulties were encountered in assembling and adjusting narrow (0.25 ins.) widths. Consequently for these tests, strips of onazote 0.5 ins. wide were used and this raises the failing load, having the same effect as an increase in the value of E of the onazote. Widths of strip and onazote were the same in the case of the 0.5 in. wide test pieces. Thickness of the

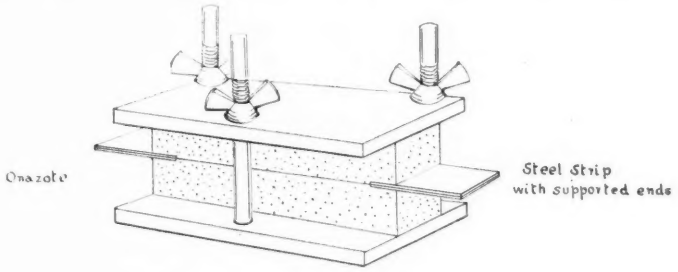


FIG. 18.

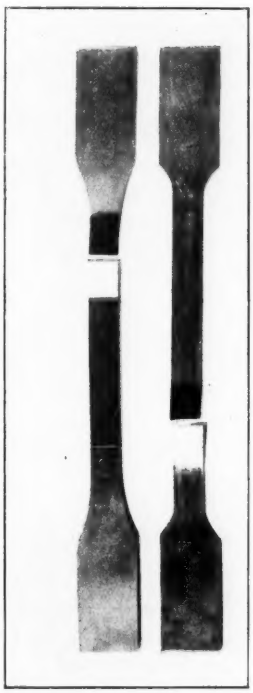


FIG. 19.

onazote was in most cases 0.5 ins., although experiments with other thicknesses were also made. The strip with end supports and two pieces of onazote were placed in a simple steel clamp consisting of two plates with three adjusting screws fitted with wing nuts. A transverse load of 10 lb. was applied by weights and the nuts tightened so that the transverse load was maintained after removal of

the weight. Check experiments showed that a variation in the magnitude of this load up to 50 lbs. had little effect. The arrangement is shown in Fig. 18.

When the test piece and clamp were in position, a small gap was left between clamp and grips so that the load was taken by the strip only.

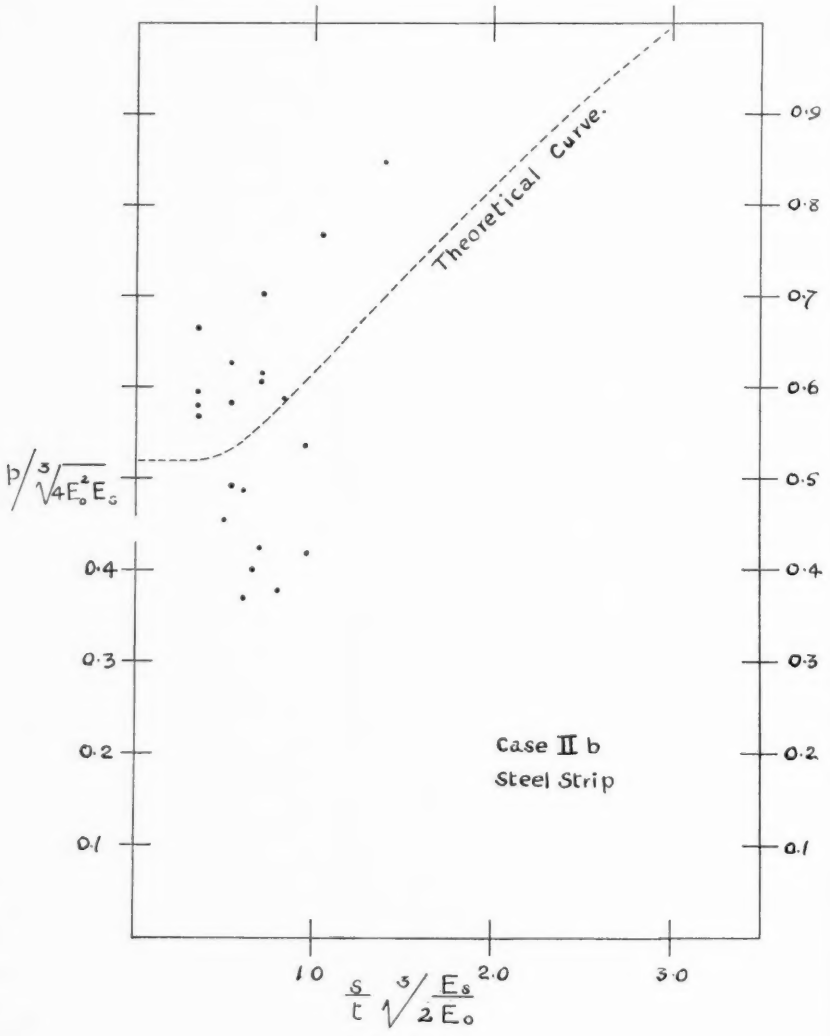


FIG. 20.

The critical failing load was unmistakable except in the case of thin strip with low density onazote support. Three types of failure of the strip were met with. (1) No permanent distortion was produced in the strip. On removal of load it straightened out, but an impression remained in the onazote. This type of failure occurred chiefly with low density onazote and thin strip. (2) The strip

was bent but not broken. (3) The strip cracked transversely, the ends being sharply bent and embedded in the onazote. Complete fracture of the strip usually occurred with a high density onazote. Typical failures are illustrated in Fig. 19.

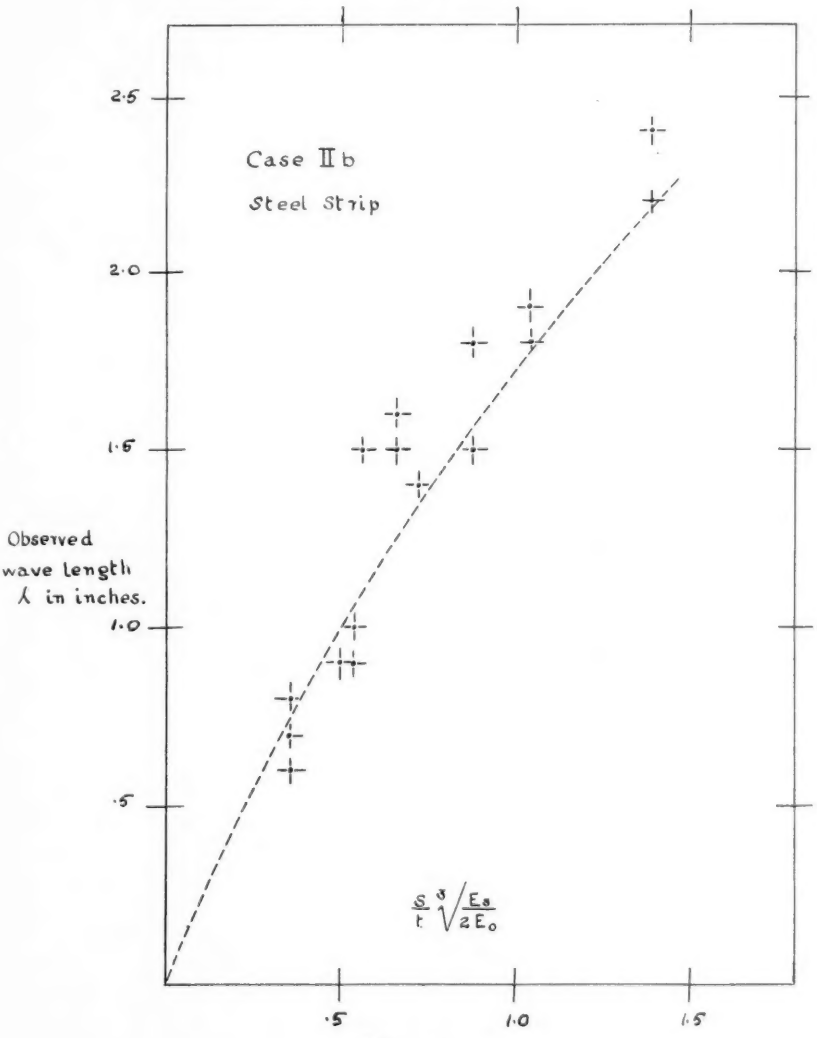


FIG. 21.

The corrugations made in the strip when it failed left impressions in both parts of the onazote although the strip itself might show only one large bend and fracture. From these impressions the wave length, λ, of the corrugations was obtained. This method can only be used if the strip deforms elastically, as in the case of steel. If any plastic distortion occurs, the impressions in the onazote may be misleading and any corrugations in the strip itself will vary in amplitude

TABLE II.

CASE II (*b*). SHAPED TEST PIECES. OVERALL LENGTH 5 INS. PARALLEL PORTION 2.25 INS.

Material of strip, steel. $E_s = 30 \times 10^6$. $E_s^{\frac{1}{2}} = 310.72$.

s ins.	b ins.	sb ins.^{2}	P lb.	p_c lb./in.^{2} mean observed.	ρ_0	E_0	$E_0^{\frac{1}{2}}$	$E_0^{\frac{2}{3}}$	t ins.	s/t $(E_s/2E_0)^{\frac{1}{3}}$	λ/t ins. from curves.	λ ins. from curves.	λ ins. observed.	$p/(4E_0^2 E_s)^{\frac{1}{3}}$ from curves.	pc lb./in.^{2} computed.
0.02	.25	.005	120												
			120	24,000	.0757	1410	11.21	125.8	.5	.879	3.12	1.56	1.5	.595	37,800
0.02	.25	.005	240												
			200										1.5		
			225	44,000	.1235	3325	14.92	222.8	.5	.66	2.50	1.25	1.6	.552	60,700
0.02	.25	.005	120												
			125	24,500	.0489	1135	10.43	108.8	.5	.944	3.28	1.64	—	.609	32,600
0.015	.25	.00375	200										0.9		
			205	53,900	.1035	2580	13.72	188.0	.5	.538	2.17	1.09	1.0	.535	49,500
0.015	.25	.00375	170												
			170	45,400	.0772	2575	13.72	188.0	.5	.538	2.17	1.09	0.9	.535	49,500
0.015	.25	.00375	90												
			100	25,350	.0757	1410	11.21	125.8	.5	.959	3.31	1.65	—	.610	37,800
0.015	.25	.00375	170												
			200	49,300	.1235	3250	14.81	220.0	.5	.499	2.01	1.00	0.9	.530	57,400
0.015	.50	.0075	180												
			125												
			165	20,900	.0489	675	8.77	77.0	.5	.842	3.00	1.50	—	.587	20,100

0.015	.50	.0075	430											
			440	58,000	.1035	2580	13.72	188.0	.5	.538	2.17	1.09	—	.535	49,500
0.010	.25	.0025	82											
			100	36,400	.1035	2580	13.72	188.0	.5	.359	1.5	0.75	0.6	.520	33,200
0.010	.25	.0025	45											
			50	18,500	.0478	675	8.77	77.0	.5	.561	2.2	1.1	1.5	.540	20,500
0.010	.50	.005	50											
			55	10,500	.0424	356	7.08	50.2	.5	.696	2.55	1.27	—	.560	13,850
0.010	.50	.005	200										0.7	
			225	42,500	.1035	2580	13 72	188.0	.5	.359	1.5	0.75	0.8	.520	33,200
0.010	.50	.005	190	38,000	.0772	2575	13.72	188.0	.5	.359	1.5	0.75	—	.520	33,200
0.010	.50	.005	70	14,000	.0489	675	8.77	77.0	.5	.561	2.2	1.1	—	.540	20,500
0.010	.50	.005	65											
			85	15.000	.0424	356	7.08	50.2	.5	.696	2.55	1.27	—	.560	13,850
0.010	.50	.005	180											
			190	37,000	.1035	2580	13.72	188.0	.5	.359	1.5	0.75	—	.520	33,200
0.020	.25	.005	102										2.2	
			100	21,200	.0424	356	7.08	50.2	5	1.39	4.38	2.19	2.4	.700	17,300
0 020	'25	.005	327											
			315											
			350	66,140	.1035	2580	13.72	188.0	.5	.718	2.7	1.35	—	.562	52,000
0 020	.25	.005	285	57,000	.0772	2575	13.72	187.7	.5	.718	2.7	1.35	1.4	.562	52,000
0.015	.25	.00375	70										1.9	
			72.5	19,000	.0424	356	7.08	50.2	.5	1.042	3.55	1.77	1·8	.630	15,600

according to the amount of compression in the strip. This was particularly noticeable in elektron and duralumin.

The results obtained in the case of steel are given in Table II and Figs. 20, 21, where they may be compared with the theoretical curves. The agreement is good in the case of the predicted and observed wave lengths.

CASE II (*b*). TESTS WITH DURALUMIN, ELEKTRON, BIRCH PLY.

Owing to the necessity of using thicker strip for these tests, only a high density onazote provided a suitable medium, so that $(s/t)\,(E_s/2\,E_o)^{\frac{1}{3}}$ was less than 0.4. Under these conditions the theoretical failing stress is of the same order or even higher than the yield point of the metals or the compressive strength of the plywood. For example, with a value of $E_o = 2{,}250$ lb./in.^{2} for the onazote, the calculated value of p_c for the duralumin is 34,400 lb./ins.^{2}, whereas the yield point was found to be 34,450 lb./in.^{2}. But, in fact, unlike steel, both duralumin and elektron have an indefinite yield point so that failure may occur at stresses considerably below the calculated value, and in the particular case quoted, failure occurred at a stress of 22,750 lb./in.^{2}.

Corrugations were formed in the strip, but as noted above, they are no reliable guide to the wave length at the moment of failure.

CASE III (*a*). SUPPORTING MEDIUM OF FINITE THICKNESS WITH FREE BACK. COMPLETE ADHESION BETWEEN SURFACES.

The conditions for the development of corrugations as described in Part I require that the value $(s/t)\,(E_s/2\,E_o)^{\frac{1}{3}}$ must be less than 0.4. Only the thinnest steel strip (0.005 ins.) could be used with the higher density onazotes, otherwise the thickness of onazote would have to be increased excessively. The length of the test pieces (L) must be such that L/t lies below the limiting L/t curve of Figs. 8 and 9. Consequently short test pieces are required, but these must be longer than the wave length of the corrugations.

The test pieces were prepared by cleaning the metal strip with benzene and using Semtex cement to fix them to the onazote. Shaped test pieces were first tried, but were discarded in favour of straight strip, as it was found very difficult to cut the onazote to fit the test piece. Moreover, failure so often occurred in the shoulder and the true failing stress could not be calculated. The same difficulty was experienced as in the case of II (*b*), of preventing failure at the extreme ends of the strip. Supports were provided by pushing in between steel and onazote, four small pieces of a thicker strip having pointed ends, after the onazote had been fixed by the Semtex cement. This ensured perfect contact between onazote and steel the whole length of the strip and there was no weak spot or gap where the supports ended.

Results are given in Table III for strips originally cut 3 ins. in length, of which 1 in. is enclosed by the two clamps. The effective length, L, is therefore 2 ins. and this includes end supports to the strip. In the case of two results of test length 5 ins. the value L/t is near the limit possible for the thickness of onazote.

CASE IV (*a*). SUPPORTING MEDIUM OF FINITE THICKNESS WITH SKIN ON BOTH FACES. COMPLETE ADHESION BETWEEN SURFACES. TESTS WITH SPRING STEEL.

In order that failure shall occur by the formation of corrugations with this combination of skin and support the value of $(s/t)\,(E_s/E_o)^{\frac{1}{3}}$ must be less than 0.35 (see Fig. 13). Consequently only thin strip 0.005 ins. thick could be used with the low density onazote, unless the thickness of the onazote was increased unduly. With higher density onazote, strip thickness of 0.01 ins. was possible. A constant thickness of onazote was a necessity in designing a suitable method of holding the test pieces. These were prepared as follows:—Two strips of steel

TABLE III.

CASE III (*a*).

Material of strip, steel. $E_s = 30 \times 10^6$. $E_s^{\frac{1}{3}} = 310.72$.

s ins.	b ins.	sb ins.^{2}	P lb.	p_c lb./in.^{2} mean observed.	ρ_c	E	$E^{\frac{1}{3}}$	$E_c^{\frac{2}{3}}$	t ins.	L ins.	L/t	s/t $(E_s/2E_c)^{\frac{1}{3}}$	$\sigma = .5$ p $(4E_c^2E_s)^{\frac{1}{3}}$	$\sigma = .5$ p_c lb./in.^{2} computed.	$\sigma = .25$ p $(4E^2E_s)^{\frac{1}{3}}$	$\sigma = .25$ p_c lb./in.^{2} computed.
0.005	.25	.00125	65	52,000	.1235	3200	14.74	216.7	.75	5	6.67	.115	.542	58,100	.572	61,400
0.005	.25	.00125	75	60,000	.1235	3200	14.74	216.7	1.0	5	5	.0836	.542	58,100	.572	61,400
0.005	.50	.0025	110													
			200													
			200													
			175	68,400	.134	3390	15.02	225.6	.75	2	2.66	.1083	.542	60,100	.572	64,900
0.005	.50	.0025	150													
			170													
			175	66,000	.125	3300	14.88	222.2	1.0	2	2.0	.0848	.542	59,500	.572	62,600
0.005	.50	.0025	90													
			90													
			100	36,700	.058	1000	10	100	.75	2	2.66	.164	.542	26,800	.572	28,200

TABLE IV.

CASE IV (*a*).

Length of strip, 6 ins. Material of strip, steel.

s ins.	b ins.	sb in.^{2}	P lb.	p_c lb./in.^{2} mean observed.	p_0	E	$E^{\frac{1}{2}}$	$E^{\frac{2}{3}}$	t ins.	$s/t\,(E_s E_0)^{\frac{1}{2}}$	λ/t ins. from curves.	λ ins. from curves.	λ ins. observed.	$p/(E_s^2/E_0)^{\frac{1}{3}}$	p_c lb./in.^{2} computed.
0.005	0.50	.005	110												
			125												
			125												
			125												
			150										1.0		
			150										1.0		
			170										0.8		
			165	28,000	.058	1000	10	100	.75	.205	.84	.63	0.8	.570	17,700
0.005	.25	.0025	85	34,000	.058	1000	10	100	.75	.205	.84	.63	1.0	.570	17,700
0.005	.50	.005	185												
			200												
			275												
			315												
			250										1.0		
			260	49,400	.134	3390	15.02	225.6	.75	.136	.57	.428	.05	.572	40,130
0 01	.50	.01	550												
			450												
			500										.8		
			375	46,800	.134	3390	15.02	225.6	.75	.274	1.12	.84	.85	.562	39,400
				Material of strip duralumin. Length of strip 5 ins.											
0.013	.50	.013	225												
			240												
			290												
			255												
			205												
			255												
			290	20,000	.104	2250	13.10	171.7	.75	.292	1.32	.99	—	.558	21,200

5 or 6 ins. long,* were stuck with Semtex cement on both sides of the onazote, which was 0.75 ins. thick and of the same width as the strip, but 1 inch shorter than the steel. The steel thus projected 0.5 ins. beyond the onazote at each end. The combination was heated at 70°C. under a light weight to ensure a good and uniform contact and to reduce the possibility of waves forming in the steel strips before testing. When fully set, T-shaped steel supports were stuck in with more cement at each end, so that the centre portion of the T fitted between the two steel strips and made contact with the onazote. Care was taken to see that the ends of the strips bore equally on the supports at each end and that these were as far as possible parallel. The arrangement can be seen in Fig. 22. When the cement attaching the ends had set, the outsides of the strips were supported at the ends by additional strips 1.0 ins. long tapered to a point and enclosed by a clamp. When all precautions were taken and the load applied through steel balls at each end, no bending of the test piece was detected until failure occurred. This consisted in the collapse inwards of one of the steel strips, which might even fracture. The final arrangement for holding the test pieces is shown in Fig. 22, which also shows the type of failure considered satisfactory.

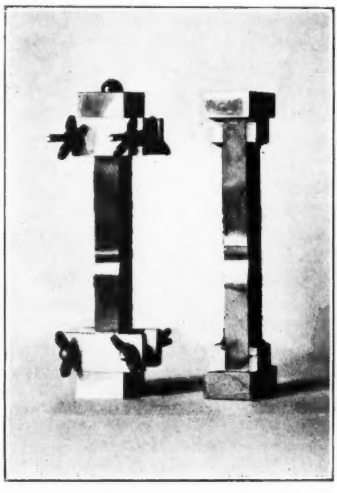


FIG. 22.

A very large proportion of tests have been omitted from the final results given in Table IV. The two commonest causes of unsatisfactory tests were the splitting off of a steel strip due to bad adhesion of the cement and failure near the supporting ends. The latter was due to a potentially weak spot where the onazote met the steel support and sometimes to a tendency of the clamp to pinch in the strips if the steel support did not coincide exactly with the distance between the strips when they were attached to the onazote. Too low values in the failing load would be expected from such causes.

Too high values might be caused by curvature along the axis of the steel strips, arising from a non-uniform layer of cement or shrinkage of the cement while setting. This effect was noticed in test pieces built up with thin wide strip, *i.e.*, 0.005 inch thick and 1 inch wide, and the use of such material was discontinued. Even with the thicker, narrower strip, however, the values given in Table IV are

* There is no possibility of a quasi-Euler buckling between supports in this case. See p. 18, Part I.

higher than those predicted by the theory, though the discrepancy becomes less as the thickness of the strip increases, and in the case of duralumin where thicker strip still was used, the agreement is satisfactory.

The influence of Semtex cement must be considered in this connection, but this also appears to be negligible. If the cement be considered to increase the flexural rigidity of the steel strip, the layer used should have the effect of increasing E_s by about $7\frac{1}{2}$ per cent. and the critical stress therefore by about $2\frac{1}{2}$ per cent.

Only an approximate measurement of the wave length was possible in this case. The figures given are the distances between the beginning of inward bending of the strip, and these were obtained by placing a straight edge along the face and, on looking at the specimen from the side, noticing the point at which derivation from the straight occurred. Such measurements could only be made when failure took place in the middle of the test piece.

Tests with Duralumin.

Test pieces were constructed and tests carried out in a similar way to the above with duralumin strip 0.013 ins. thick and 0.5 ins. wide. Owing to the thickness of the strip only high density onazote could be used to satisfy the condition that $(s/t)\,(E_s/E_o)^{\frac{1}{3}}$ should be less than 0.35.

These tests gave satisfactory agreement with the theory.

Acknowledgments.

We wish to express our thanks to Professor C. E. Inglis and to Messrs. the de Havilland Aircraft Co., Ltd., for the facilities provided for this work.

Summary.

This paper gives a theoretical and experimental investigation of the strengths of thin sheets stabilised in various ways by adjacent layers of a material with a value of Young's modulus small in relation to that of the thin sheet. The analytical results are expressed in the form of curves which enable a rapid computation to be made of the strength and of the wave length of the corrugations produced at failure. Not all the eight cases investigated analytically are capable of experimental test, but where experimental tests have been carried out a reasonably satisfactory agreement with the theoretical curves has been obtained.

References.

1. M. A. Biot. Journ. Applied Mechanics (1937).
2. W. Fairbairn. Conway and Menai Tubular Bridges (1849).
3. W. Granholm. On the elastic stability of piles surrounded by a supporting medium (Stockholm, 1929).
4. C. Dornier. B.P. 504, 423.
5. Th. von Kármán. P. Stock. B.P. 235,884.
6. M. E. Reissner. Proc. Nat. Acad. Sci., 23, p. 328 (1937).
7. S. Timoshenko. Ann. Ponts et Chaussees (1913).
8. H. Wagner. Zeits. f. Flug. u. Motorluftschiffahrt, p. 241 (1928).
9. S. Timoshenko. Theory of Elastic Stability (New York, 1936), p. 139.

Appendix I.

The stress-function and the stress-deflection ratios appropriate to the various sections are collected in this appendix. No attempt is made to reproduce the analysis as it is too cumbersome. In the functions for cases I-III the skin is at $y=0$, and the medium lies on that side for which y is negative. For cases II and III the back is at $\alpha y=-\beta$. For the double-faced medium of case IV the skins are at $\alpha y=\pm\beta/2$.

I (a).

$$V=-\{(q_m \sin \alpha x)/\alpha^2\}\left[1+\tfrac{1}{2}(1+\sigma_o)\,\alpha y\right]e^{\alpha y}$$

$$q/r_o=(2E_o\alpha)/\{(1+\sigma_o)(3-\sigma_o)\}.$$

I (*b*) (Biot).

$$V = -\{(q_m \sin \alpha x)/\alpha^2\}(1+\alpha y)\, e^{\alpha y}$$
$$q/v_o = E_o a/2.$$

II (*a*).

$$V = -\{(q_m \sin \alpha x)/\alpha^2\}\{\cosh \alpha y - \tfrac{1}{2}(1+\sigma_o)\alpha y \sinh \alpha y\}$$
$$+\{\sinh \alpha y\,[2(3-\sigma_o)\sinh^2\beta - (1+\sigma_o)^2\beta^2]$$
$$-\alpha y \cosh \alpha y\,(1+\sigma_o)(3-\sigma_o)\sinh^2\beta\}/\{2[(3-\sigma_o)\sinh\beta\cosh\beta + (1+\sigma_o)\beta]\}$$
$$q/v_o = \{2E_o a[(3-\sigma_o)\sinh\beta\cosh\beta$$
$$+(1+\sigma_o)\beta]\}/\{(1+\sigma_o)(3-\sigma_o)^2\sinh^2\beta - (1+\sigma_o)^3\beta^2\}.$$

II (*b*).

$$V = -\{(q_m \sin \alpha x)/\alpha^2\}\{\cosh \alpha y$$
$$-[\alpha y \sinh \alpha y \sinh\beta\cosh\beta - (\sinh \alpha y - \alpha y \cosh \alpha y)\sinh^2\beta]/[\sinh\beta\cosh\beta+\beta]\}$$
$$q/v_o = \{E_o a(\sinh\beta\cosh\beta+\beta)\}/(2\sinh^2\beta).$$

III (*a*).

$$V = -\{(q_m \sin \alpha x)/\alpha^2\}[\cosh \alpha y - \tfrac{1}{2}(1+\sigma_o)\alpha y \sinh \alpha y$$
$$+\{\sinh \alpha y\,[2\cosh^2\beta + (1+\sigma_o)\beta^2]$$
$$-\alpha y \cosh \alpha y\,[(1+\sigma_o)\cosh^2\beta + (1-\sigma_o)]\}/\{2[\sinh\beta\cosh\beta - \beta]\}]$$
$$q/v_o = [2E_o a(\sinh\beta\cosh\beta - \beta)]/[(1+\sigma_o)(3-\sigma_o)\sinh^2\beta + (1+\sigma_o)^2\beta^2 + 4].$$

III (*b*).

$$V = -\{(q_m \sin \alpha x)/\alpha^2\}\{\cosh \alpha y$$
$$-[\alpha y \sinh \alpha y \sinh^2\beta - (\sinh \alpha y - \alpha y \cosh \alpha y)(\sinh\beta\cosh\beta+\beta)]/[\sinh^2\beta - \beta^2]\}$$
$$q/v_o = [E_o a(\sinh\beta - \beta^2)]/[2(\sinh\beta\cosh\beta+\beta)].$$

IV (*a*).

$$V = -\{q_m \sin \alpha x\}/\{2\alpha^2\sinh^2(\beta/2)\}\{\sinh \alpha y\,[2\sinh(\beta/2)$$
$$+(1+\sigma_o)(\beta/2)\cosh(\beta/2)] - \alpha y \cosh \alpha y\,(1+\sigma_o)\sinh(\beta/2)\}$$
$$q/v_o = [2E_o a(\cosh\beta - 1)]/[(1+\sigma_o)(3-\sigma_o)\sinh\beta + (1+\sigma_o)^2\beta].$$

IV (*b*).

$$V = -[\{2q_m \sin \alpha x\}/\{\alpha^2(\sinh\beta - \beta)\}]\{\sinh \alpha y\,[\cosh(\beta/2) + (\beta/2)\sinh(\beta/2)]$$
$$-\alpha y \cosh \alpha y \cosh(\beta/2)\}$$
$$q/v_o = \{E_o a(\sinh\beta - \beta)\}/\{2(\cosh\beta + 1)\}.$$

Appendix II.

The term quasi-Euler is used to distinguish the failure which occurs by buckling over the greatest wave length which the supports allow from the corrugated failure fixed by the minimum condition. Although the skin fails in an Euler curve it is not a true Euler effect, as the critical stress is increased by the force necessary to displace the medium. When the skin does not receive directional constraint at the supports, the equivalent wave length is equal to twice the spacing of the supports ($\lambda = 2L$): when the supports afford complete local constraint in the direction of the skin the wave length is equal to the spacing ($\lambda = L$).

With the double-faced medium the quasi-Euler failure corresponds very closely to that discussed by Timoshenko (9) in which the Euler critical load is reduced by lack of shearing rigidity. In this sense, the Euler load is the large value for the composite construction bending as a unit, but the shearing rigidity is so small that the strength is vastly reduced and the whole conception without much meaning.

When the construction is not continuous through a support it is assumed that the attachment is such as to maintain the original direction of the transverse plane of the ends of the two skins.

NEW RESEARCH ON THE USE OF HARDENING PLASTICS FOR AIRCRAFT CONSTRUCTION.*

By Wilhelm Kuech.

Laminated materials incorporating plastics seem to be especially well suited for highly stressed aircraft components, by reason of their good strength properties. Paper, fabric and wood veneers treated with plastics on a phenolic basis were tested with regard to their strength, especially in bending, shear, absorbed energy in impact bending, notching strength and in their resistance against moisture. Further, the behaviour of compressed plastics was studied at different temperatures under static and dynamic loads. A part of the research was extended to pure phenol resin and to thermoplastics based on methacrylate and polyvinylchloride. The bonding properties of laminated compressed plastics were established. Concluding, some experiments relating to the practical manufacture of aeroplane components are communicated.

Contents.

I. Introductory.
II. Strength properties. Tests relating to the methods of taking sample test pieces, shape of test pieces and of the loading speed upon the strength. Moisture resistance.

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* Translated from Jahrbuch, 1938, der Deutsche Luftfahr Forschung.

Guide for the Numerical Tables. Table

Properties of Com

1		2	3	4	5
	Material.	Specific Weight. γ	Strength, in kg./sq. cm. Tensile. σ_B	Compressive. σ_{-B}	Bending. σ'_B
	Pure Resin, not hardened	1.25-1.35	200-400	800-1000	350-550
	Pure Resin, hardened	1.27	600	2800	451-1270
Compressed Mixture Plastics	Asbestos	1.47-2.18	250-350	1200-2000	500-1430
	Wood Dust	1.30-1.50	250-450	1800-2550	600-1000
	Cardboard Strips	1.39	—	—	1415–2000
	Cardboard Waste	1.35	—	—	1020-1318
	Fabric Waste	1.20-1.40	250-500	1500-2200	508-1400
Compressed Laminated Plastics.	Resin-bonded Paper ...	1.37-1.40	1007-2053	1700-2090	1535-3000
	Resin-bonded Fabric ...	1.30-1.40	384-1170	1300-2210	687-1910
	Resin-bonded Wood Veneers	1.02-1.35	1520-3590	1230-2160	1760-3540
	Vulcan Fibre	1.50	838-892	1080-1180	1680-1770
	Pine Wood	0.5	1000	500	800
	Duralumin	2.8	4470	13700	9340
	Steel	7.85	12000	10500	—

[1] Circular bending tests. [2] Plane bending tests.

III. Shear strength of laminated compressed plastics.
IV. Static and dynamic bending tests at different temperatures. Notching strength.
V. Glueing strength of compressed laminated plastics.
VI. Components made from compressed laminated plastics (spars, shells).
VII. Summary.
VIII. Literature.

I. Introductory.

Because of the efforts to use home-grown materials, as far as possible, modern compressed plastics have become especially interesting for aircraft production.

The following report intends to complete the information existing of the physical and mechanical properties of compressed plastics, with a special consideration of the requirements of aeroplane construction. Tests are communicated dealing with the design of spars and shells made from compressed laminated plastics.

Generally, the research work has been restricted to materials based on phenol resins, as these represent at present the most important group of thermo-hardening plastics.

II. Strength Properties. Tests Relating to the Influences of Methods of Taking Sample Test Pieces, Shape of Test Pieces and of the Loading Speed upon Strength. Moisture Resistance.

In Table I strength figures, hardness values and linear expansion under the influence of heat are compiled for pure phenolic resin, compressed mixtures and laminated plastics, from test results already published. As a comparison, the corresponding values of other materials in use for aeronautical constructions are included.

I.

PRESSED PHENOPLASTICS.

6	7	8	9	10	11	12	13	14	15
Impact Bending Strength (cm. kg./sq. cm.).	Young's Modulus (kg./sq. cm.).	Alternating Bending Strength (kg./sq. cm.).	Torsional Strength (kg./sq. cm.).	Modulus of Shear. (kg./sq. cm.).	Coefficient of Linear Expansion $10-6$	σ_B/γ	σ_{-B}/γ	σ'_B/γ	E/γ
4-8	27-35000	80-100[1]	150-250	10-12000	—	3.0	7.4	4.1	260
3-24	61-64000	—	—	—	45	4.7	22.0	8.2	480
3.5-33	70-212000	—	—	—	15-30	2.4	13.6	4.8	1090
5-10	40-100000	255-275[2]	—	—	38-50	3.5	19.6	7.7	770
15-23	109-112000	—	—	—	—	—	—	14.4	805
10-16	102-106000	—	—	—	—	—	—	9.8	784
11-14	40-100000	—	—	—	20-50	4.2	18.3	11.7	830
54	83-149000	500[1]	320	25000	—	15.0	14.0	20.0	1060
14-57	58-136000	{ 225-270[1] / 184-405[2] }	425	22000	15-24	8.0	16.0	13.0	973
75-100	200-311000	760[2]	—	—	—	27.0	16.0	26.0	2300
77-90	79-82000	—	—	—	—	6.0	7.9	11.3	547
—	110000	—	—	—	—	20.0	10.0	16.0	2200
—	726000	—	—	—	—	16.0	49.0	33.0	2600
—	2100000	—	—	—	—	15.0	13.4	—	2680

Columns 12 to 15 refer to the maximum values.

The compressed mixture plastics have a relatively poor strength. Their suitability for stressed components can, therefore, not yet be finally judged. It would only appear justified if, by the addition of appropriate filling materials, the strength properties could be considerably improved, without impairing the plastic qualities.

Laminated compressed plastics, especially resin-bonded wood veneers (laminated "improved wood")* and paper sheets impregnated with synthetic resin (resin-bonded paper), however, can be considered competitive with other aeronautical materials, according to present standards. Practically, at the moment, all tests with aircraft components such as wings, shells and airscrews are restricted to resin-bonded paper or to resin-bonded fabric. Experiments with resin-bonded wood veneers have only to a small extent become known, in spite of the fact that this material has a higher mechanical strength than all the other compressed plastics. The reason may be that it proves less suitable for pressing in moulds.

For the subsequent research work, the following testing methods have been employed:—

Compression strength: Cubes of 10 mm. sides.

Bending strength: Test pieces of 120 × 15 × 10 mm., freely supported at both ends. Single central load, 100 mm. distance between supports.

Fixed supports (in accordance with the V.D.E. requirements) proved unsuitable for exact measurements. Otherwise, it has been established that both methods give values for the ultimate strength which are well in agreement.

Impact bending strength: Test pieces of 120 × 15 × 10 mm., in accordance with D.I.N. 7,701 specification.

Tensile strength: Flat bars of 230 × 20 mm. × thickness of board or 5 mm. With thicker laminated boards, the test pieces were cut out with the width parallel to the laminations.

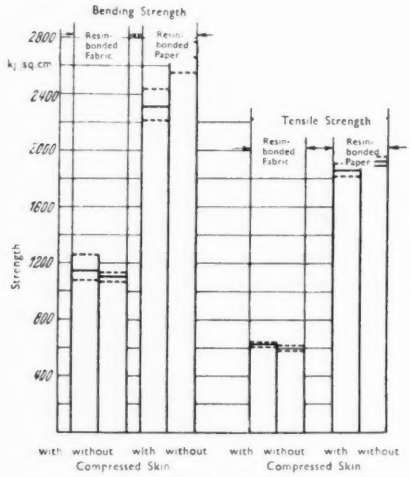


FIG. 1.

Influence of the surface condition of test pieces upon the strength of resin-bonded paper and resin-bonded fabric.

* Under wooden material of this kind such material is understood which is made from *Beech* veneers impregnated with synthetic resin and compressed under high pressure ("Lignofol"). The expression "Hardwood" which is often used is misleading, as this term is already in common use in the wood trade and in the general wood manufacturing industry.

As shown in Fig. 1, the strength, under static loads anyway, is not impaired if the outer skin is removed. Samples taken with the width perpendicular to the laminations vary much in their test results and are, therefore, not to be recommended.

Fig. 2 shows the strength of commercial resin-bonded paper and fabric, the test pieces being taken in various ways. One direction of the boards gives the optimum strength values. From this, the conclusion may be reached that the fibre structure of the paper sheets has a definite orientation, and that the fabric

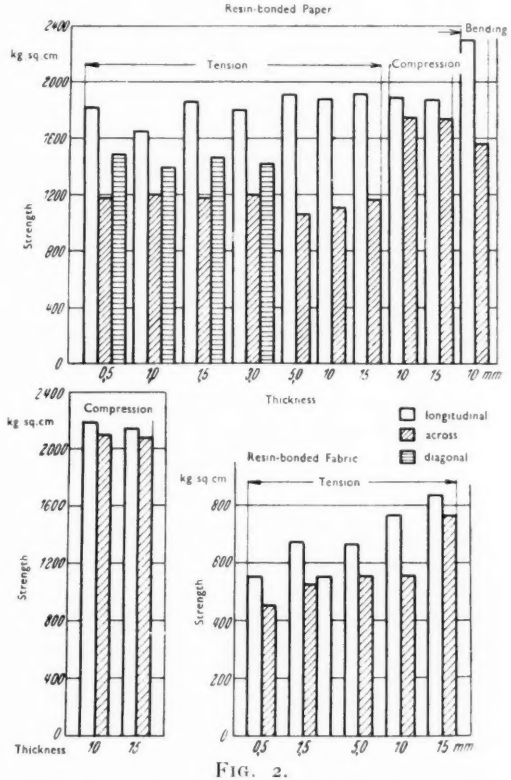


FIG. 2.

Strength of resin-bonded paper and resin-bonded fabric in relation to the direction of the boards.

layers have differences in the threads forming warp and weft. The difference is very marked with the resin-bonded paper; under tensile loads it amounts to as much as 80 per cent., relative to the minimum values observed.

The strength in compression is not defined by the filling material but is governed by the resin and is, consequently, independent of the direction of the laminations. For the constructional use of such compressed boards, it appears to be necessary to mark the direction of maximum strength, so that the material can be used to the full extent. In cases in which an evenly distributed strength is asked for, crosswise arranged laminations should be used. Tests made with such a special resin-impregnated paper resulted in bending strengths of 2,500 kg./sq. cm. and 2,160 kg./sq. cm. in both main directions.

Fig. 3 gives the result of strength tests on resin-bonded paper and fabric boards of different thicknesses, taken from the same batch. While paper material generally shows the same values, with resin-bonded fabric, the strength is greatly increased with the thickness of the boards. Because the conditions of the manufacture were not known, an explanation of this somewhat surprising fact cannot yet be given.

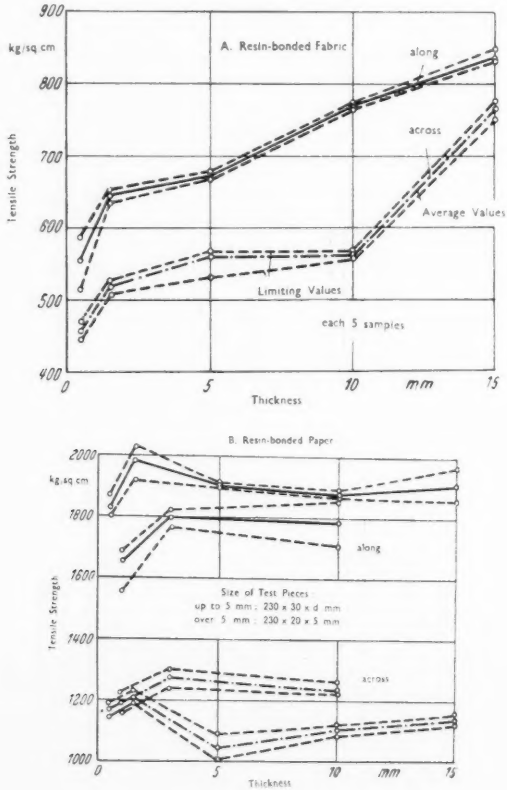
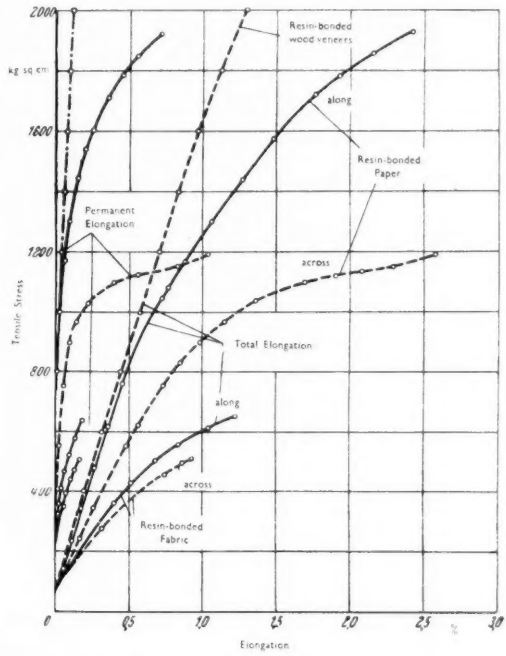


FIG. 3.

Tensile strength of laminated compressed plastics at different thickness of the boards.

Figs. 4 and 5 show deformations of resin-bonded wood veneers, paper and fabric under the action of tensile and compressive loads, without regard to the elastic hysteresis. The loading and unloading speed was 250 kg./sq. cm. per minute. In Fig. 6, the calculated modulus of deformation due to the loading $\Delta\sigma/\Delta\epsilon$ in relation to the stress is shown. Resin-bonded wood veneers have a much higher stiffness than resin-bonded paper and fabric. Further, impregnated paper and fabric materials suffer severe plastic deformations at relatively low stresses. The decline of the M value starts with these materials at 200 and 420 kg./sq. sm., respectively, in comparison with about 700 kg./sq. cm. obtained with impregnated wood veneers. During the tension tests with resin-bonded paper, a regular flowing could be observed in direction of the minimum strength.



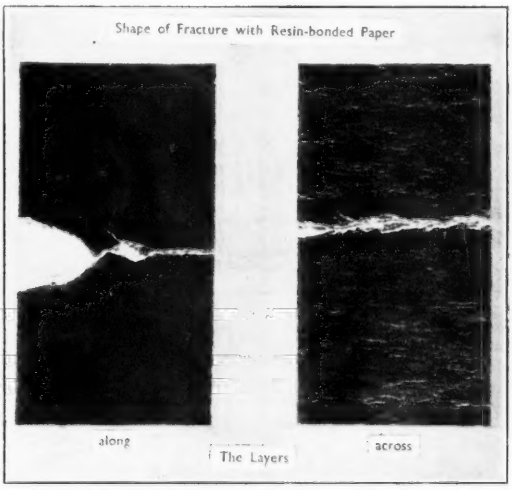


FIG. 4.

Tensile stress and elongation of laminated compressed plastics.

The unorthodox behaviour of boards in the different directions can also be learned from the shape of the fracture (Fig. 4). With samples taken across the layers, cracks within the resin appear before the ultimate load is reached, on account of the higher yielding qualities of the paper.

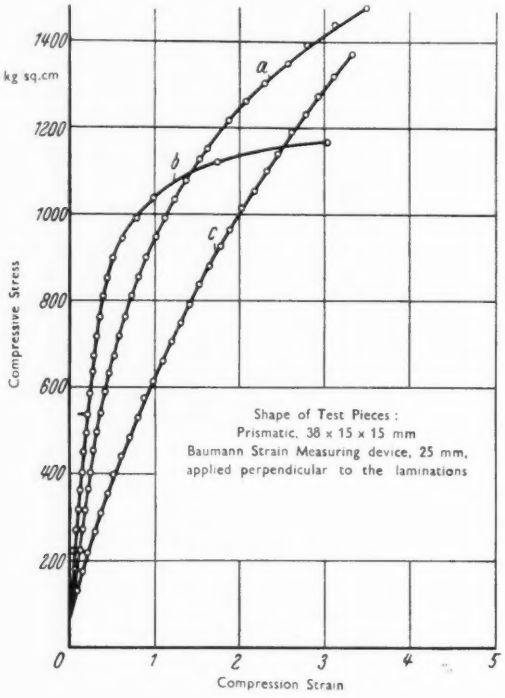


FIG. 5.

Compressive stress and compressive strain of laminated compressed plastics (total compression):—

(a) Resin-bonded paper;
(b) Resin-bonded wood veneers;
(c) Resin-bonded fabric.

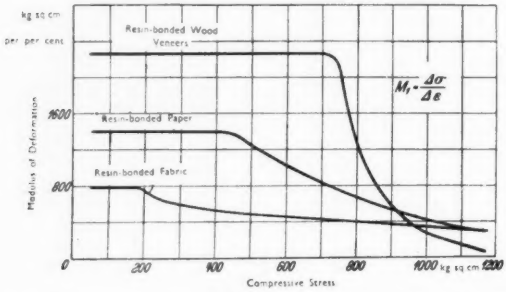


FIG. 6.

Deformation modulus of loading relative to the load (compression test).

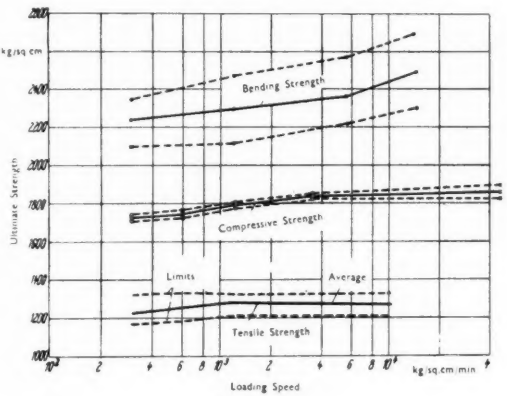


FIG. 7.

Influence of loading speed upon the strength of resin-bonded paper.

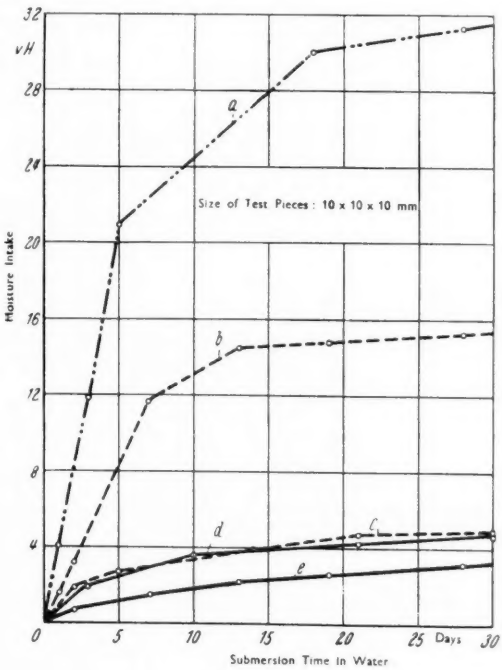


FIG. 8.

Moisture intake of laminated compressed plastics:—

(*a*) *Resin-bonded wood veneers;*
(*b*) *Resin-bonded paper N;*
(*c*) *Resin-bonded paper S;*
(*d*) *Resin-bonded fabric S;*
(*e*) *Resin-bonded fabric N.*

Fig. 7 shows the relation between loading speed and strength observed on resin-bonded paper. One can realise from bending and compression tests that a decline in strength will set in as soon as a certain test time is exceeded. Tests are at present under way for observation of the endurance strength properties of compressed impregnated materials, in order to explore fully the phenomena concerned.

Figs. 8 to 10 show the influence of moisture on the strength and on the resistance against deformation, with compressed laminated plastics. Evidently, one and the same material can behave in a very different way. So, for instance, with the standard quality *N* of impregnated paper, the decrease in strengths observed

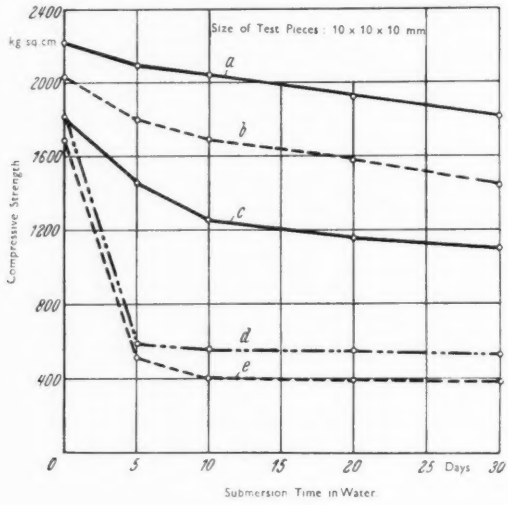


FIG. 9.

Loss of strength with laminated compressed plastics after different periods of submersion in water. Average values out of five tests.

(*a*) *Resin-bonded fabric N;*
(*b*) *Resin-bonded paper S;*
(*c*) *Resin-bonded fabric S;*
(*d*) *Resin-bonded wood veneers;*
(*e*) *Resin-bonded paper S.*

after five days under water was 70 per cent., with the special quality *S* only 11 per cent. however. For such constructional parts which are exposed to the weather, an inspection of boards with regard to their moisture resistance is, therefore, indicated. Eventually, an additional surface protection may be required. Resin-bonded fabric is much less affected by moisture. The high sensitiveness of resin-bonded wood veneers against moisture may be due to a relatively low resin content of the boards tested.

III. Shear Strength of Laminated Compressed Plastics.

The research covers resin-bonded fabric, paper and wood veneers of thicknesses between 0.5 and 20 mm. From the thin boards (0.5 to 2.5 mm.) flat strips of 160 × 35 mm., from the thicker ones (15 to 20 mm.) round rods of 10 mm. diameter were cut and tested in double shear according to Figs. 11*a* and 11*b*. In

addition, double shear tests were done in accordance with the provisional specification D.I.N. D.V.M. 2,186, valid for wood (Fig. 11c). The shear strength was observed in both main directions. Further, shear was applied in the plane and across the laminations, alternatively. The resin-impregnated wood materials were made from compressed veneers arranged parallel with their grain. With the thicker boards, three different materials having a specific gravity of 0.81, 1.05 and 1.35 were tested.

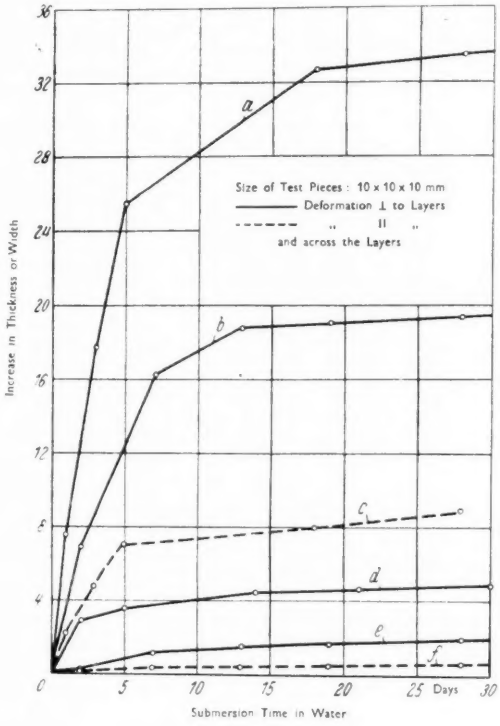


FIG. 10.

Shape retaining quality of laminated compressed plastics under the influence of moisture:—

(*a*) *Resin-bonded wood veneers;*
(*b*) *Resin-bonded paper N;*
(*c*) *Resin-bonded wood veneers;*
(*d*) *Resin-bonded paper S;*
(*e*) *Resin-bonded fabric N;*
(*f*) *Resin-bonded fabric and resin-bonded paper N and S.*

The results of these tests are given in Fig. 11. Impregnated paper and fabric show in both directions nearly identical shear strengths. Resin-bonded wood veneers, however, show a very poor shear strength parallel to the grain. This can be improved by incorporating crosswise veneers, at the expense of the strength across the grain, of course. Impregnated paper has a lower strength with thin boards than with thick ones, due to the relatively higher proportion of filling material. With resin-bonded fabric, the shear strength observed in the plane of

the layers was up to 60 per cent., with resin-bonded paper only 10 per cent. of the strength perpendicular to the layers, as a consequence of a less strong adhesion between single layers with the paper material. Test method " *c* " resulted in bending failures with paper material, because of the very high strength; thus the results obtained were not considered suitable. The shear strength of resin-bonded paper is up to 200 per cent. higher than with resin-bonded wood tested along the grain. This fact should be taken into account for the design of bolted and riveted joints.

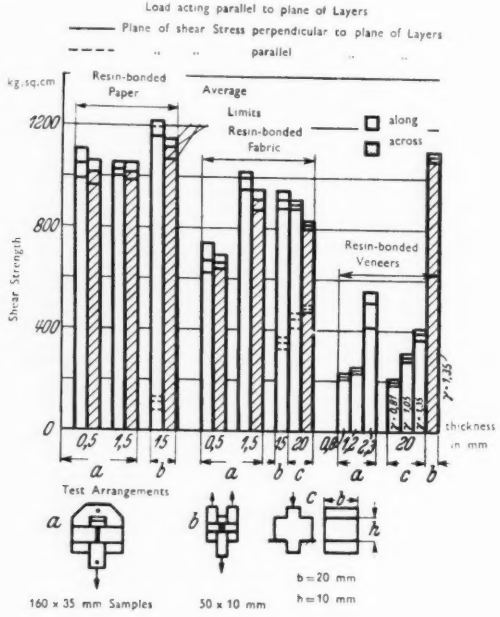


FIG. 11.

Shear strength of laminated compressed plastics.

IV. STATIC AND DYNAMIC BENDING TESTS AT DIFFERENT TEMPERATURES. NOTCHING STRENGTH.

For room temperatures and for temperatures between $-60°$ and $+90°C.$, the static bending strength and the energy absorption at the impact bending test were observed, employing notched and unnotched test pieces. For the notching impact test, normal bending test samples were provided by means of a saw cut on the tension side with a rectangular cross-groove of 2 mm. width and 3.3 mm. depth, in accordance with the new standardisation valid for compressed plastics (Lit. 46). In addition, pointed and rounded notches were tested with resin-bonded paper and with methacrylate, in order to determine the influence of the cross-sectional shape of the notch. The impact and notching test samples were kept in a mixture of carbon dioxide ice and alcohol, or in an electrically heated glycerine bath in order to secure the temperatures required (60 minutes storage time) and immediately afterwards tested to destruction. Any absorption of moisture was prevented. For the static bending tests, the bending table of the material testing machine was fitted as a container for retaining the temperature of the samples, so that the ultimate strength could be ascertained at the temperature desired. The research was extended to polymerisates of polyvinylchloride and of methyl-

acrylates, besides to materials based on phenolic plastics. This was due to the efforts made to use thermoplastics for the production of laminated compressed plastics on grounds of the fact that their heat resisting properties have been improved recently.

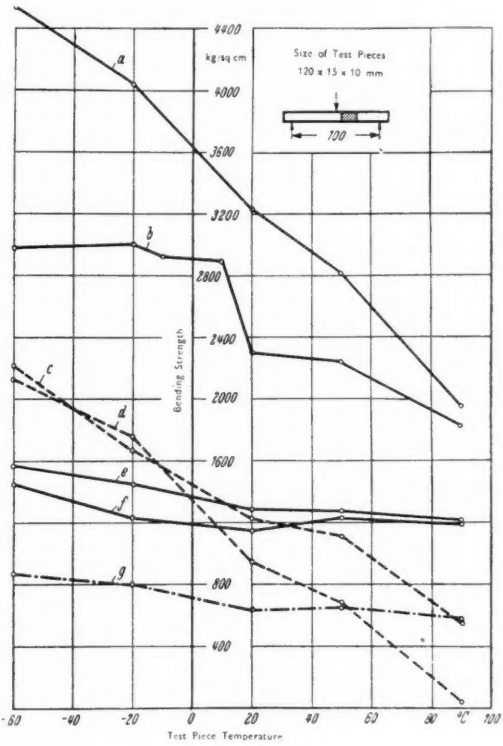


FIG. 12.

Static bending strength of plastics at different temperatures:—

(*a*) *Resin-bonded wood veneers;*
(*b*) *Resin-bonded paper;*
(*c*) *Methacrylate;*
(*d*) *Polyvinylchloride;*
(*e*) *Resin-bonded fabric;*
(*f*) *Pure phenolic resin;*
(*g*) *Linen waste.*

Fig. 12 and Table II show the results of the static bending tests at different temperatures. Of great interest is the fact that bonded paper and bonded wood veneers possess a considerably higher strength at low temperatures and lowered strength figures at high temperatures, while pure phenolic resins, bonded fabric and compressed mixture plastics do not show any variation of importance. It is probable that within the fairly inelastic paper and veneer layers, internal strains are setting in immediately after the pressing process during the manufacture of the boards and caused by the shrinkage of the resin during the cooling period. It appears that these internal stresses are increased by a further cooling of the

material, and that they are relieving, during a bending test at low temperature, part of the tension stresses which are decisive for the rupture. On the other hand, when the samples are subjected to heat, these internal stresses will be normalised due to the expansion of the resin parts and, therefore, the tension strength observed will be lower than at room temperature.

TABLE II.

STATIC BENDING STRENGTH OF PLASTICS AT DIFFERENT TEMPERATURES.

For sizes of test pieces and testing arrangement, see Fig. 12.

Load applied perpendicular to the plane of the layers.

Number of samples for each test, 5.

Material	Temperature. C.	Bending Strength Extreme Values. (kg./sq. cm.)	Average Values (kg. sq. cm.).
Resin-bonded Wood Veneers	−60	4270 to 4920	4533
	−40	3910 ,, 4160	4053
	+20	3110 ,, 3360	3230
	+50	2740 ,, 2920	2827
	+90	1900 ,, 2020	1948
Resin-bonded Paper	−60	2850 ,, 3100	2980
	−20	2860 ,, 3080	3000
	−10	2800 ,, 3000	2920
	+10	2860 ,, 2930	2890
	+20	2280 ,, 2320	2300
	+50	2190 ,, 2270	2240
	+90	1800 ,, 1860	1830
Resin-bonded Fabric	−60	1540 ,, 1610	1570
	−20	1420 ,, 1450	1440
	+20	1230 ,, 1302	1276
	+50	1260 ,, 1280	1270
	+90	1200 ,, 1220	1210
Pure Phenolic Resin	−60	1300 ,, 1670	1450
	−20	1090 ,, 1490	1227
	+20	942 ,, 1370	1150
	+50	998 ,, 1490	1230
	+90	1140 ,, 1360	1210
Compressed Mixture Plastics (Linen Waste)	−60	820 ,, 1320	875
	−20	667 ,, 965	804
	+20	508 ,, 720	633
	+50	503 ,, 836	660
	+90	478 ,, 735	565
Thermoplastic Methacrylate	−60	2150 ,, 2310	2260
	−20	1590 ,, 1740	1680
	+20	990 ,, 1660	1240
	+50	1050 ,, 1130	1110
	+90	553 ,, 567	557
Thermoplastic Polyvinylchloride ...	−60	2050 ,, 2220	2130
	−20	1720 ,, 1810	1757
	+20	901 ,, 1000	950
	+50	666 ,, 692	675
	+90	—	40

With thermoplastic materials, the bending strength or the maximum stress absorbed decrease gradually down to a small value with rising temperature over the whole range. The decrease is more marked with the polymerisate of vinylchloride than with methacrylate. It appears that the development of laminated compressed plastics from thermoplastics depends upon the improvement of their heat resisting qualities, at least for such applications during which major changes of temperatures and mechanical strains are to be expected. This statement is based upon the knowledge that certain essential properties, as for instance the

compression strength of laminated compressed plastics, are governed exclusively by the behaviour of the plastics used and not by the filling material.

In Fig. 13, the results of impact bending tests are given with unnotched samples at a temperature of 20°C. With thermoplastics, the energy absorption is considerably higher than with pure phenolic resin. The application of thermoplastics for laminated compressed plastics, therefore, seems to indicate that such material will give a decreased brittleness. Polyvinylchloride and mixed polymerisates made of polyvinylchloride and other components have a higher impact bending strength than methacrylate. Among the laminated materials tested, resin-bonded fabric showed a particularly poor energy absorption. The porous fabric layers absorb the resin to a large extent, thus causing a very high resin

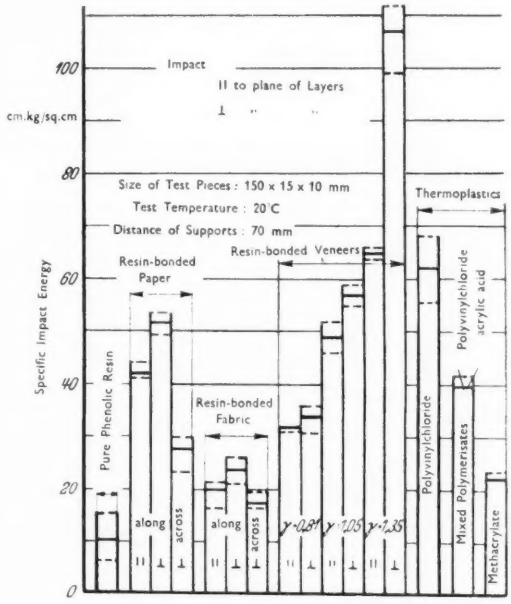


FIG. 13.
Impact energy absorption of plastics (impact bending test).

content of the boards. Surprisingly enough, with resin-bonded wood veneers, the specific value of the impact energy absorption showed an increase with increasing density. Now, generally, it is an established fact that the absorption of energy diminishes when the resin content is higher. Therefore, the fact observed with the wood material can only be caused by the higher compression of the boards, but cannot be related to a more complete impregnation of the veneers with phenolic resin.

In all cases, the impact value observed with laminated plastics is higher for an impact happening vertically to the plane of the layers than for the impact parallel to the layers. The optimum strength direction, which is particular with resin-bonded paper for one direction of the boards, was also observed during the impact bending tests.

In Fig. 14, the notching strength value K_z, *i.e.*, the ratio between energy absorption observed on a full rod to the energy absorption of a notched one, is

shown for a temperature of 20°C., in order to allow for a comparison of the notching sensitiveness of the different materials tested. The sensitiveness of the thermoplastics against notching is greatly variable, even with one and the same basic material, but is higher than with pure phenolic resin. With the laminated compressed plastics, the results obtained show a clear relation to the shear strength. Material of a high shear strength, for instance, resin-bonded paper, has a high notching sensitivity, for an impact parallel to the layers anyway, while resin-bonded wood veneers seems practically to lack any sensitivity against notches. This may be explained by the strain distribution within the material while subjected to the notched bending test. With a rod having a notch on the tension side, shear forces are acting in the boundary layer between the undamaged part and the part the fibres of which have been severed. The magnitude of these strains depends upon the resistance of the material against shear in direction of the shear strain acting, and this is governing the notch effect. For an impact

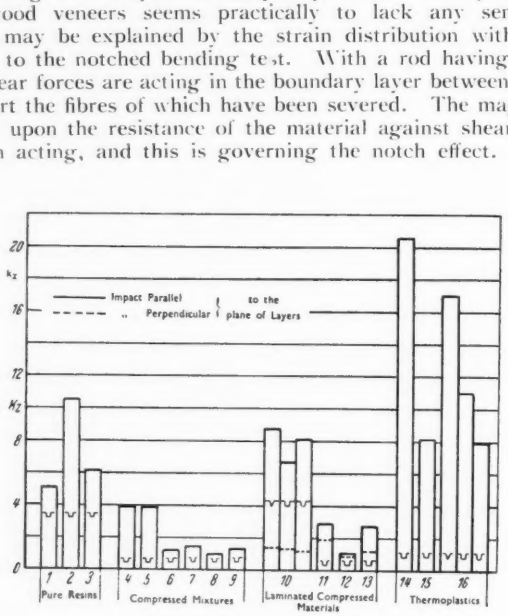


FIG. 14.

Notching strength of plastics (impact bending test).

perpendicular to the laminations, the notch effect is practically neutralised because of the splitting of the samples in direction of the laminations which originates from the bottom of the notch. For the examination of the notching sensitivity, it should be, therefore, more reliable to do the impact tests parallel to the layers and not perpendicular to them as required by specification D.I.N. 7,701, with laminated materials.

In Fig. 15, the impact bending strength at high and at low temperatures is shown. With thermoplastic materials, it is remarkable that methacrylate shows small influence of temperature, while with polymerisate of vinylchloride, the specific impact energy value increased steeply with the temperature. A test series with notched samples of polyvinylchloride showed a smaller influence of temperature upon the values. The beginning of steep rise of the impact energy curve shifts from about −10°C. to 40°C. due to notching. Of the hardening compressed plastics, pure phenolic resin gives nearly identical values over the whole range of temperature, while laminated compressed plastics have smaller impact energy values at low temperatures.

Within the temperature limits employed during these tests, no permanent structural change within the materials subjected to tests took place. Brought back to normal temperatures, in every case the original properties were obtained.

V. Glueing Properties of Compressed Laminated Plastics.

Compressed laminated plastics, especially resin-impregnated wood veneers, have more inferior plastic moulding qualities than compressed mixture plastics. Further, with moulded laminated plastics, a variation in the strength qualities can be expected. In view of these disadvantages, it seems advisable to build up components of an intricate shape such as wings, etc., from standard parts such as boards and profiles with the help of bonding cements or glues. This seems more advantageous as the construction of expensive moulds can be eliminated in this way; such moulds would also impair any future modification with the component concerned which would involve a modification of the mould.

In aeronautical construction, the use of glueing has hitherto been restricted nearly exclusively to joints between wooden parts. In accordance with the common view, two factors were considered to be essential for the strength of a glued joint, namely, a mechanical anchoring of the glue within pores of the wood, and secondly, the adhesion between the glue and the wood. Obviously, with

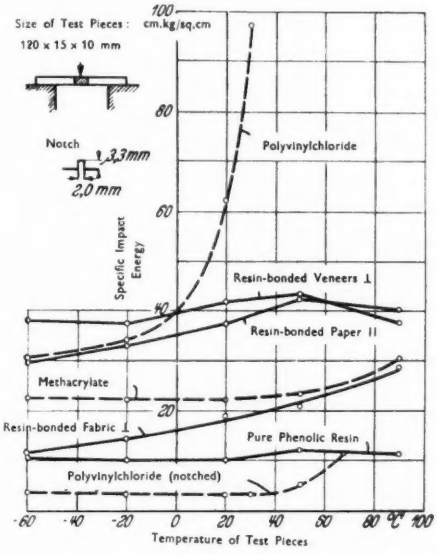


Fig. 15.

Impact energy absorption of plastics at different temperatures (impact and notched impact bending test).

compressed plastics, a depth effect of the cementing means is excluded because of the very homogeneous and dense structure of the material. For the reliability of glued joints between compressed plastics, therefore, the adhesive force between the cementing means and the material is decisive.

Up to now, few tests have been published dealing with the glueing of compressed plastics. N. A. de Bruyne (Lit. 26) deals with the importance of glueing compressed plastics and refers to strength tests with glued joints between resin-bonded fabric. For these tests, casein glue as well as certain resin cements made from methacrylates and formaldehydes, which are thermo-hardening, have been used. The highest strength was obtained with synthetic resin cements based upon formaldehyde. De Bruyne refers in the same report to research work of G. Staeger, Zurich, which deals with bonding tests between smooth surfaces. Tests

made with bonding between metals showed good strength for cements based upon phenolic and cresolic resins. Heating results in a loss of strength with these cements with continued condensation, but this loss disappears again during prolongated heating.

The research work of the D.V.L. was carried out on resin-bonded wood veneers, resin-bonded paper and resin-bonded fabric. As a bonding means, " Kaurit " synthetic resin glue was used, a glue which is based on aminoplastics. Kaurit is made exclusively from home-grown raw materials. A great amount of experience is already available with the practical handling of this glue in the manufacture of wooden aeroplanes. The hardening can be done without heating at normal room temperatures, which means a valuable simplification in the handling. Previous tests had shown that with Kaurit very high strength values can be obtained, especially with hard materials.

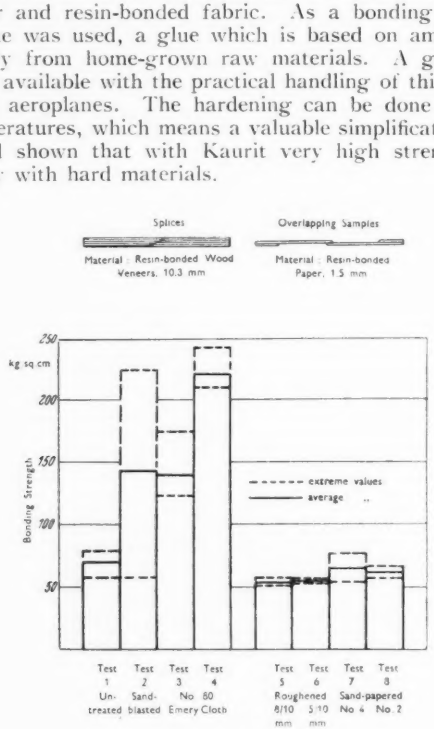


FIG. 16.

Influence of the surface condition of the glueing surfaces upon the strength of glued joints between compressed plastics. Bonding cement, Kaurit glue with cold hardener " red." Time of clamping pressure applied, 18 *hours. Number of samples for each test,* 5.

The first practical tests did not give satisfactory results. In view of this, it became necessary to examine more thoroughly the factors which influence the bonding strength.

Fig. 16 shows the influence of the surface condition of the areas to be glued on the bonding strength. Splices made in resin-bonded wood veneers were glued and tested for strength with an untreated condition of the glueing areas, after sandblasting them, and after treatment of these areas with No. 80 emery cloth.

In the first case, the strength values were surprisingly low. Test pieces with the glueing areas roughened by sandblasting prior to the glueing showed on the average a definitely improved strength, but also great variations in strength. Because of variations in the local hardness of the material (caused by unequal impregnation of the veneers with resin) or because of an unequal acting of the sandblast, small uneven spots are created which cannot be levelled out by the

pressure similar to the behaviour of wooden parts under action of the clamping pressure, but which result in an unsufficient fit at these uneven spots, due to the hardness of the compressed material. A treatment with No. 80 emery cloth gave surprisingly good strength results (on the average, up to 223 kg./sq. cm.). The conclusion is that—contrary to the experience with solid wood, the glueing surfaces of which, generally, have to be roughened in order to secure a good bond—with compressed plastics, the bonding strength increases with the degree of smoothness imparted to the surfaces of the joint before glueing. It is obvious that with hard plastics, a reliable joint can only be secured with entirely level glueing surfaces which give an equal pressure distribution resulting in a thin glue layer with very strong adhesive forces.

Similar tests with overlapping samples of resin-bonded paper (see also Fig. 16) are well in agreement with this result. Here again with plane glueing surfaces (ground with No. 4 and No. 2 sandpaper), a higher bonding strength was observed than with roughened surfaces.

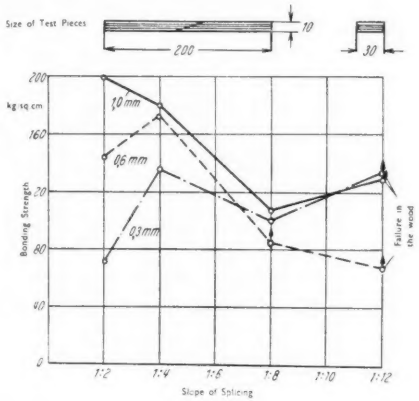


FIG. 17.

Strength of glueings with resin-bonded wood veneers at different lengths of splices and with different thicknesses of veneers. Bonding cement, Kaurit glue with cold hardener "red." Time of clamping pressure applied, 18 hours.

In Fig. 17 the results of tests are shown made with glued splices on resin-bonded wood veneers having different thicknesses of the veneers (1.0, 0.6, 0.3 mm.), at different lengths of the splices. With splices having a slope of up to 1 : 4, the strength observed varies directly with the veneer thickness in a way that the bonding strength is increasing with an increasing veneer thickness. It can be assumed that the thicker veneers are less impregnated with synthetic resin. The boards having the thicker veneers contain cells which are partly free of resin, thus giving an excellent anchoring basis for the glue at a very sloped cut, and this results in an increased bonding strength. With longer slopes of the splices (1 : 12), however, the board built up from the thinnest veneers gave the maximum strength. A joint like this is similar to a longitudinal one. In this case, the material at the glued joint is subjected to high shear forces against which thicker veneers having a smaller resin content than thinner ones, can only offer a relatively small resistance. With a longer slope of the splice, the failure always took place in the wooden material and not in the joint.

The influence of the clamping pressure required for the glueing was examined with resin-bonded paper (Fig. 18). The diagram shows an optimum value at

about 30 kg./sq. cm. But also at very low glueing pressures quite a good bonding strength can be obtained.

A research concerning the optimum spreading of the glue gave the best values with a very thin glue layer brought up to the glueing surfaces (Table III).

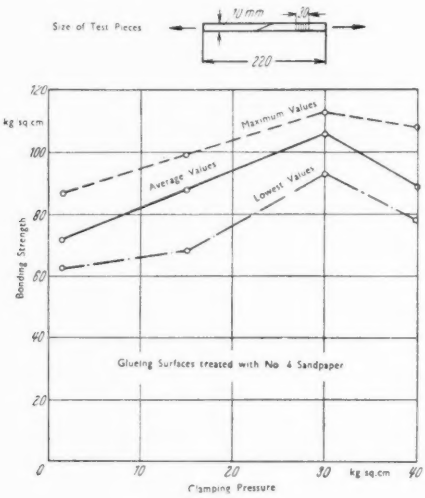


FIG. 18.

Influence of the clamping pressure upon the strength of glued joints on compressed plastics.

Number of samples, six.
Material, resin-bonded paper.
Bonding cement, Kaurit glue with cold hardener "red."
Time of clamping pressure applied, 18 hours.

TABLE III.

STRENGTH OF GLUED SPLICES MADE WITH RESIN-BONDED WOOD VENEERS AT DIFFERENT THICKNESSES OF THE GLUE.

Adhesive, Kaurit glue with cold hardener "red"; time of clamping pressure, 18 hours; size of test pieces, see Fig. 17; number of samples for each test, 6.

Method of Glueing.	Bonding Strength. Extreme Values. (kg. sq cm).	Average Values. (kg /sq cm.).
Normal Spreading of Hardener	118 to 147	127
Very Thin Spreading of Hardener	119 ,, 153	134
286 gr./sq. m. Glue Spreading	120 ,, 161	139
132 gr./sq. m. Glue Spreading	140 ,, 163	152

Table IV gives the strength of spliced and overlapping joints on resin-bonded paper, resin-bonded fabric, and on resin-bonded wood veneers as well as of joints between compressed plastics and wood or resin-bonded veneers; in addition, tests relating to the moisture content of the samples are included. Far the best glueing qualities were observed with resin-bonded wood veneers. Compressed impregnated fabric boards gave a 'surprisingly' poor strength. The reason is apparently this: During the grinding of the surfaces to be glued, small resin

particles are caused to break out of the fibres and allow the fabric fibres to swell; this results in a relatively high roughness (Fig. 19).

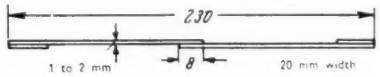
TABLE IV.

STRENGTH OF GLUED JOINTS MADE WITH LAMINATED COMPRESSED PLASTICS.

Adhesive, Kaurit glue with cold hardener "red"; the glueing surfaces were treated with No. 80 emery cloth; time of clamping pressure, 18 hours; number of samples for each test, 5.

Material.	Condition of samples.	Bonding Strength. Extreme values. (kg./sq. cm.).	Average values. (kg./sq. cm.).	Wet to dry ratio.
shape of test pieces: DVL splicing samples; 1.4 slope of splice.				
Resin-bonded paper ...	dry	133 to 163	144	—
	wet*	111 ,, 159	137	0.95
Resin-bonded fabric ...	dry	53 ,, 64	60	—
	wet	47 ,, 63	55	0.92
Resin-bonded wood veneers	dry	211 ,, 243	222	—
	wet	80 ,, 120	107	0.48

Shape of test pieces:



Resin-bonded fabric ...	dry	44 to 51	48
Resin-bonded paper ...	dry	43 ,, 62	53
Resin-bonded wood veneers,	dry	62 ,, 67	64

Shape of test pieces:

A-B	Resin-bonded paper ...	dry	69 to 71	70
A-B	Resin-bonded fabric ...	dry	67 ,, 73	69
A-B	Resin-bonded wood veneers,	dry	67 ,, 103	89†
A	Resin-bonded paper ...	dry	43 ,, 46	45†
B	Pinewood			
A	Resin-bonded paper ...	dry	62 ,, 75	66
B	Laminated Beech veneers, acc. to TV Bu. 25			

Against moisture, the glueing was found to be highly insensitive, because of the good hygroscopic qualities of compressed plastics. After storing for 100 hours in water, the bonding strength is still 92-95 per cent. of the values observed on dry samples, with resin-bonded fabric and with resin-bonded paper. With resin-impregnated wood veneers, the wet strength dropped to only 48 per cent. of the very high dry strength. In spite of the embedding of the wood veneers in resin, the hygroscopic property of the wood is still partly retained.

With the exception of resin-bonded fabric, glued joints between compressed plastics and wood gave higher values with Kaurit glue than hitherto observed in wooden aeroplane construction.

* Subsequent to a submersion of 100 hours in water.
† Failure due to shear in the wood.

The research referred to enables us to consider the problem of glueing laminated compressed plastics as solved. Tests made with other cementing materials resulted in lower strength figures and are, therefore, not communicated.

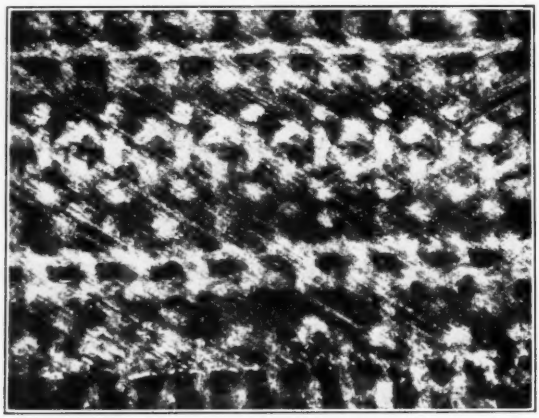


FIG. 19.

Section through resin-bonded fabric, seven times enlarged.

VI. COMPONENTS MADE FROM COMPRESSED LAMINATED PLASTICS.*

As a practical test, experimental spars and shells were constructed from laminated compressed plastics and subjected to strength tests.

1. SPARS.

In accordance with Fig. 20, two I-section spar samples were made. The material was resin-bonded paper and resin-bonded wood veneers. For the component constructed from impregnated paper, strips provided with hollowed out portions, as shown in Fig. 20, were glued by means of Kaurit cold glue to a board forming the basis throughout the whole length. In order to secure an equal pressure distribution, the laminations were kept relatively thin. The final shape was obtained by milling.

The spar constructed from impregnated wood veneers was made out of a full plank, in order to facilitate the manufacture. In practice, it will be possible, of course, to press such a component in one step, especially with impregnated paper material. But for the present tests, expensive press moulds had to be avoided in order to secure quickly figures for the strength of aircraft components made from the plastics under discussion.

The spars were supported at both ends and centrally loaded by a single load to destruction. At the same time, the total deformation and the permanent one in the middle of the spar were measured. The results are given in Fig. 20, and they are compared in Table V with former tests which had been made with a wooden spar and with a box spar riveted together from boards of resin-bonded paper and resin-bonded wood veneers respectively.

The failure of the spars took place by lateral buckling under simultaneous shearing of the profile flanges in the plane of the laminations, by action of shear stresses. The load supported by the impregnated paper spar was only about

* This work has been assisted by the supply of material and the construction of press moulds by the Dynamit A.-G. at Troisdorf, the Roemmler A.-G. at Spremberg, and the Siemens-Schuckertwerke A.-G. at Berlin.

50 per cent. of the load taken by the impregnated wood spar, and did not reach the values observed with the much lighter solid wood spar tested previously. The poor stiffness of the resin-bonded paper led at small loads to large deformations which caused the fracture to begin.

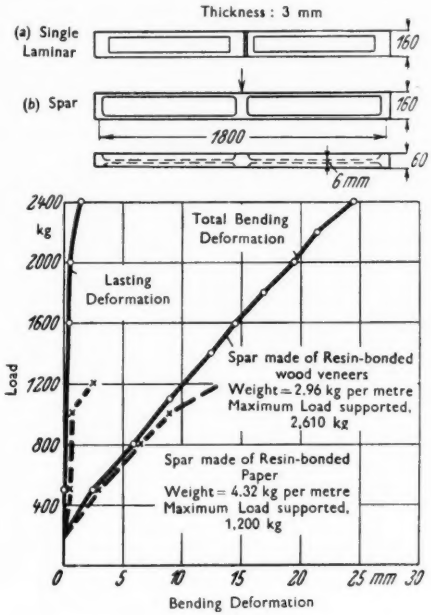


FIG. 20.

Bending tests with spars made of laminated compressed plastics.

TABLE V.

BENDING TESTS WITH SPARS MADE OF COMPRESSED PLASTICS.

Sizes and loading as shown in Fig. 20.

	New Tests.		Former Tests (Box Spars).	
	Resin-bonded Paper.	Resin-bonded Wood Veneers.	Wooden Spar.	Spar made from Plastics.
Outer Dimensions, mm.	2000 × 160 × 60		2000 × 160 × 75	
Distance of Supports, mm. ...	1800			
Weight, kg./m.	4.32	2.96	3.24	3.12
Ultimate Load, kg.	1200	2610	2590	2190
Maximum of Bending Deformation, mm.	13.5	26.5	30.0	39.0

The application of resin-bonded wood veneers, however, offers advantages against a solid wood construction. The tests indicate that for the development of stressed components for aeronautical use, resin-bonded wood veneers are especially suited. The application of resin-bonded paper requires careful attention in order to secure a sufficient stiffness for the components concerned.

2. SHELLS.

For these tests as well, the simplest possible equipment was to be used. Consequently, the shell samples were constructed similar to those known in metal

aeroplane design, having a basis plate (usually the skin) which is stiffened by stringers of Z or U section. As materials resin-bonded paper and resin-bonded wood veneers were employed. The press moulds required were constructed by the D.V.L.

The moulding of Z sections from impregnated wood veneers had to be accomplished with a parallel arrangement of the grain of the veneers, owing to the sharp curvature, so that the forming took place across the grain. The flexibility of wood veneers along the grain is poor. The disadvantage of such an arrangement is that the stringer profiles produced have a poor strength in a direction across the grain. It has, however, been found that this disadvantage may be overcome by placing some fabric layers impregnated with the same synthetic resin between the veneers before pressing. These insertions do not offer any resistance to the moulding process, but give a very improved coherency in a direction across the section. In this way the stringer profiles were built up with eight beech veneers of about 0.3 mm. thickness having two insertions of fabric between the third and fourth, and between the fifth and sixth veneer, respectively.

TABLE VI.

STRENGTH OF RESIN-BONDED WOOD VENEERS WITH DIFFERENT INSERTIONS.

Sizes of boards, $400 \times 470 \times 3$ mm.

Size of test pieces, $230 \times 20 \times 3$ mm.

Composite materials, 5 beech veneers, 4 insertions.

Material.	Direction of Test.	Specific Weight.	Tensile Strength: Extreme Values (kg./sq. cm.).	Tensile Strength: Average values (kg./sq. cm.)	Added Tensile Strengths (along and across the grain.) (kg./sq. cm).	Young's Modulus (kg. sq. cm.).
Veneers arranged at 90° to each other (cross-wise) ...	along	1.32	1810 to 1920	1870	2920	164000-177000
	across		875 ,, 1160	1050		140000-151000
All veneers arranged with the grain running in the same direction	along	1.35	3070 ,, 3590	3370	3537	293000-296000
	across		147 ,, 189	167		42300
Veneers in the same direction with coarse fabric insertions	along	1.37	2920 ,, 3270	3110	3367	255000-260000
	across		238 ,, 268	257		46400-52400
Veneers in the same direction with fine fabric insertions	along	1.37	2830 ,, 3470	3200	3472	284000-293000
	across		243 ,, 301	272		57800-59500
Veneers in the same direction with vellum insertions	along	1.36	2530 ,, 3170	2840	3081	263000-274000
	across		221 ,, 256	241		45900-46100

The materials were pressed by the Dynamit A.-G. at Troisdorf.

Table VI gives the properties of such compressed laminated plastics composed of veneers and fabric or paper. It is evident that the strength of impregnated wood veneers across the grain can be considerably improved by such insertions, without any appreciable loss of the strength in a longitudinal direction. After initial difficulties had been overcome, the stringer profiles were successfully moulded even without any insertions of fabric, by using crosswise arranged wood veneers. Experience showed that a pre-heating softened the veneers somewhat, which, otherwise, became very brittle as soon as the solvent used for the impregnating solution evaporated. The moulding pressure applied was 160 kg./sq. cm., with relation to the basic area, and the hardening temperature was 150°C.

Table VII shows the result of crippling load tests with the different stringer sections. For the sizes chosen, the ultimate load of the sections is generally

approximately half the compression strength of the solid material. With larger deformations (Fig. 21), the stringer sections made from resin-bonded paper gave a higher strength than the samples made from resin-bonded wood veneers. While the former showed a normal crippling fracture, test pieces made from parallel arranged veneers showed the formation of wrinkles which resulted, especially with the Z-sections, in a premature shear failure of the resin-bonded veneers along the grain (Fig. 22). These observations indicate that in cases in which the shear stiffness is important, resin-bonded paper is superior to resin-bonded wood. In Fig. 23, the ultimate crippling loads of Z-sections made from

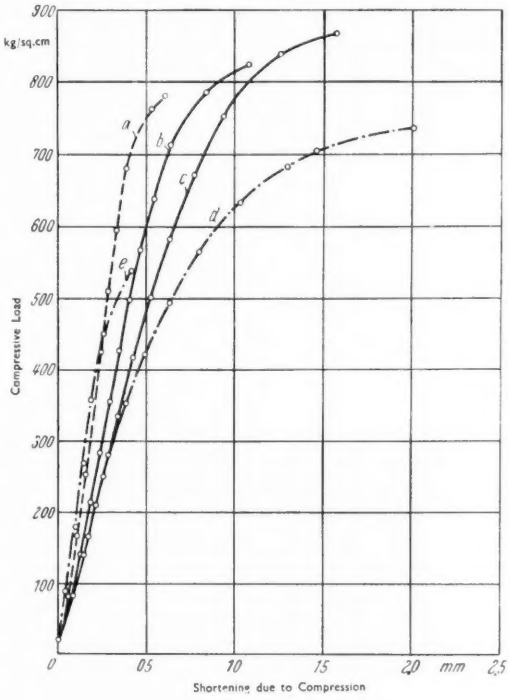


FIG. 21.

Crippling tests with stringer profiles made of resin-bonded paper and of resin-bonded wood veneers:—

(*a*) *Resin-bonded wood veneers, longitudinal grain, U-section.*
(*b*) *Resin-bonded paper, Z-section.*
(*c*) *Resin-bonded paper, U-section.*
(*d*) *Resin-bonded wood veneers, crosswise arranged laminations, U-section.*
(*e*) *Resin-bonded wood veneers, longitudinal grain. Z-section.*

crosswise arranged veneers and from longitudinally arranged veneers having fabric insertions are shown relative to the fineness ratio (length/radius of gyration). The optimum values were obtained with stringer sections moulded from veneers with fabric insertions.

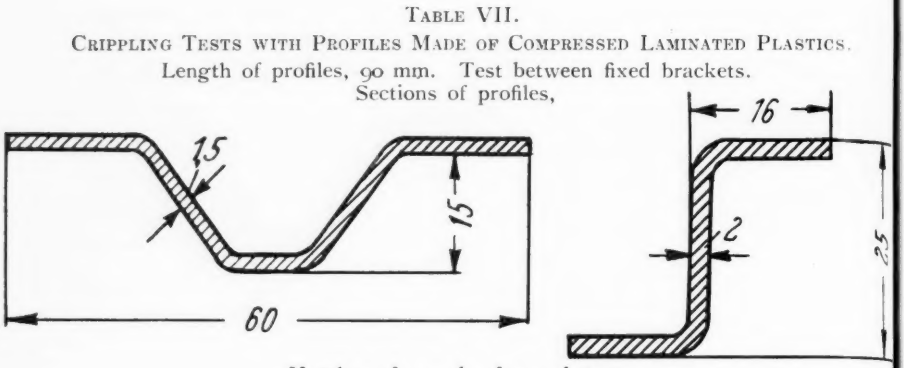
The assembly of the skin plates forming the basis and the stringer sections to shell samples (Fig. 24 and 25) was made by means of glueing with Kaurit, using the experience gained with the test work described in Chapter V of this report.

TABLE VII.

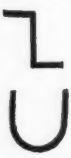
CRIPPLING TESTS WITH PROFILES MADE OF COMPRESSED LAMINATED PLASTICS.

Length of profiles, 90 mm. Test between fixed brackets.

Sections of profiles,



Number of samples for each test, 4.

Profile section	Material.	Weight (gr.)	Area of cross-section (sq. cm.).	Crippling strength of profiles σ_P (kg. sq. cm.) extreme values.	average	Compressive strength of material σ_{-B} (kg./sq. cm.).	$\frac{\sigma_P}{\sigma_{-B}}$
	Resin - bonded wood veneers (along)[1] ...	13.7	1.10	534-578	550	1570	0.35
	Resin-bonded paper ...	17.3	1.39	818-842	829	1725	0.48
	Resin - bonded wood veneers (along) ...	13.8	1.15	784-821	800	1570	0.51
	Resin - bonded wood veneers (90°)[2] ...	17.4	1.45	748-853	791	—	—
	Resin-bonded paper ...	15.4	1.22	801-866	838	1725	0.49

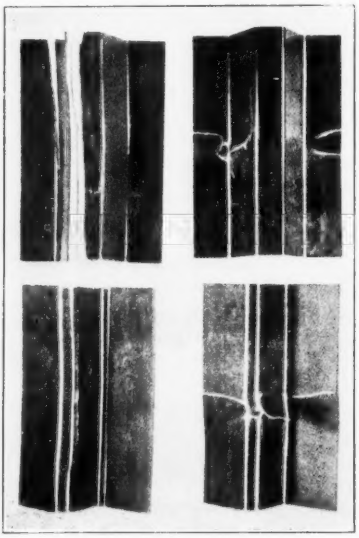


FIG. 22.

Crippling tests with sections made of laminated compressed plastics.

[1] Resin-bonded wood veneers pressed from 8 veneers with the grain arranged parallel and from fabric layers (8 veneers, 2 fabric layers).

[2] Resin-bonded wood veneers pressed from cross-wise arranged veneers.

The strength of the shells was 3,000-6,000 kg. (Table VIII) with wall thicknesses of 1.5 to 3.0 mm. and with outside dimensions of 180 × 180 mm. to 441 × 459 mm. The tests were done between fixed plates and without taking test pieces. The glueing proved to be free of any fault. In spite of marked deformations, the bonding between the skin and the stringer sections remained in the majority of cases intact. A subsequent research of the D.V.L. will ascertain in a fundamental way the influence of the design upon the strength of shells. Tests with shells having corrugations will be included. Fig. 26 shows such a sample pressed from resin-bonded paper.

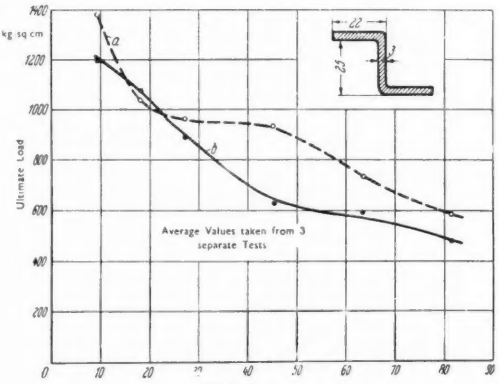


FIG. 23.

Crippling tests with Z-sections made of resin-bonded wood veneers:—
(a) Four beech veneers, the grain arranged longitudinally, with three fabric insertions.
(b) Five beech veneers, the grain crosswise arranged.

FIG. 24.
Z-shell made of resin-bonded wood veneers.

In Table IX results are given of some tests which concern a possible improvement of the strength qualities of resin-bonded paper. Three sodium cellulose layers of 1.2 mm. thickness impregnated with phenol resin were pressed together with two insertions made of steel wire mesh (0.12 mm. wire dia.; 10 wires per centimetre in both directions), under a pressure of 130 kg./sq. cm. By means of the insertions, the tensile strength and Young's modulus of the resin-bonded paper could be improved by 20-30 per cent., the increase in the specific weight only amounting to about 15 per cent.

TABLE VIII.

STRENGTH TESTS WITH SHELLS MADE OF LAMINATED COMPRESSED PLASTICS.

100 tons testing machine. Tests made between fixed brackets and without any further support.

Profile sections as shown in Table VII.

Shell No.	Profile Section.	Material.	Outer dimensions (mm.)		Stringer distance (mm.)	Thickness Basis (skin) (mm.)	Thickness Stringers (mm.)	Weight (kg.)	Ultimate load (kg.)	Remarks.
1		Resin-bonded wood veneers ...	180	180	120	2.2	1.75	0.140	3480	
2		Resin-bonded wood veneers ...	180	180	120	2.2	1.75	1.144	4050	
3		Resin-bonded wood veneers ...	278	186	120	1.5	1.5	0.177	3000	Formation of wrinkles. Joints between skin and stringers remained intact. Fig. 24.
4		Resin-bonded paper	400	459	120	2.0	2.0	0.827	4500	Formation of wrinkles. One stringer breaks away.
5		Resin-bonded paper	441	459	120	3.0	1.6	1.221	6000	Buckling of the whole shell. Fig. 25 shows the shell before the test.

TABLE IX.

IMPROVEMENT OF THE STRENGTH OF RESIN-BONDED PAPER BY MEANS OF METAL INSERTIONS.

Structure of the boards, three layers of sodium cellulose (1.2 mm.) impregnated with phenolic resin; two insertions of steel wire mesh.

Structure of the wire mesh, 0.12 mm. dia. of wire, 10 wires per centimetre in both directions.

Resin-bonded Paper.	Specific Weight. γ	Tensile Strength σ_B (kg./sq. cm).	Young's Modulus E (kg./sq. cm.)	σ_B/γ	E/γ
Without Wire Mesh ...	1.36	1400	134000	10.3	985
With Wire Mesh	1.56	1680	181000	10.8	1160
Difference in %	+14.7	+20.0	+35.0	+ 4.9	+17.8

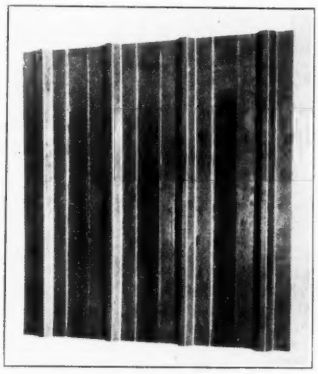


FIG. 25.
U-shell made from resin-bonded paper.

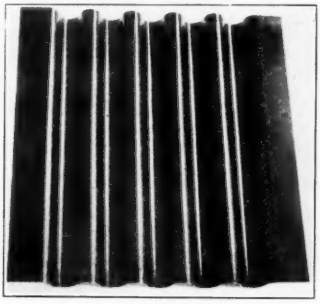


FIG. 26.
Corrugated shell compressed from resin-bonded paper.

VII. SUMMARY.

The present report refers mainly to laminated compressed plastics using phenol resins. After some general research work relating to the influence of the selection of samples, the shape of test pieces, the loading speed upon the strength

and the resistance against moisture, fundamental shear strength tests with compressed plastics are communicated. Pure phenol resins and laminated materials are compared with thermoplastics based upon methacrylate and polyvinylchloride as to bending strength, impact energy and notching strength. Tests with the behaviour of the materials at different temperatures show with resin-bonded paper and with resin-bonded veneers a marked relationship between the strength and the temperature, caused by internal strains. With thermoplastics, notches result in a lesser influence of the temperature under dynamic loads. The problem of glueing laminated compressed plastics has been solved. Cold hardening glues based upon aminoplastics give good bonding properties, provided that the glueing surfaces are properly treated prior to the glueing. Methods for the development of stringer profiles, spars and shells from laminated plastics are also described. These components were tested for strength. For stressed components, resin-bonded veneers seem especially suitable. The manufacture of formed parts from resin-bonded wood veneers by means of pressing in moulds can be made considerably easier by the use of composite laminated plastics consisting either of veneers and fabric or paper layers. Tests with resin-bonded paper provided with insertions of steel wire mesh gave an increase of 20-35 per cent. in strength.

CONVERSION FIGURES.

1 kg./sq. cm. = 14.22 lbs./sq. in.
1 mm. = 0.0394 in.
1 cm. kg./sq. cm. = 5.36 in.-lb./sq. in.
1 kg. = 2.204 lb.

VIII. LITERATURE.

1. Caldwell, F. W., and Clay, N. S. Micarta Propellers. National Advisory Committee for Aeronautics, T.N. 198, 199, 200, 201. (1924.)
2. K. Hesse, Kunstharpresstoffe. Maschinenbau, vol. 10 (1931), No. 16, pp. 540-541.
3. O. Kraemer. Kunstharzstoffe und ihre Entwicklung zum Flugzeugbaustoff. DVL Yearbook, 1933, No. VI, pp. 69-81.
4. G. Parzich. Die Daempfungseigenschaften von Nichtmetallen. Forschung, Vol. 4 (1933), No. 1, pp. 8-10.
5. M. Langley. Plastic materials for aircraft construction. Aeroplane, Vol. 49 (1935), No. 1272, pp. 441-446, and No. 1275, pp. 529-532.
6. A. Schob, R. Nitsche, E. Salewski. Die Pruefung von Fertigstuecken aus Isolier-Presstoffen auf Werkstoffeigenschaften. Plastische Massen, No. 12 (1935), and No. 1 (1936), p. 10.
7. Towards the moulded aeroplane. Aeroplane. Vol. 49 (1935), p. 432.
8. A discussion about plastics. Aeroplane, Vol. 49 (1935), pp. 529-532.
9. Atwood plane completed. Aviation, Vol. 34 (1935), p. 64.
10. The behaviour of a brittle material at failure. J. Appl. Mech., Vol. 3 (Sept., 1936), No. 3, pp. 99-103.
11. S. D. Shinkle, A. E. Brooks, G. H. Cady. A new plastic material. Ind. Enging. Chem. (Ind. Ed.), Vol 28 (1936), No. 3 (8), pp. 275-280.
12. G. Kraenzlein. Systematik der Kunststoffe. Angew. Chemie, Vol. 49 (1936), No. 52, pp. 917-926.
13. W. Roehrs, Pruefung und Bewertung von Kunstharz-Erzeugnissen. Kunststoffe, Vol 26 (1936), No. 3, pp. 47-54.
14. J. Delmonte. Plastics appear on aircraft. J. Aeron. Sci., Vol. 14 (1936), No. 1, pp. 12-18.
15. Improving the creep stress of plastics. Aeroplane, Vol. 50 (1936), No. 1291, pp. 231-232.
16. G. de Havilland. Filled resins and aircraft construction. J. Aeron. Sci., Vol. 3 (1936), No. 10, pp. 356-357.
17. N. A. de Bruyne, J. N. Maas. A property of synthetic resins. Aircraft Engineering, Vol. 1936, No. 92, pp. 289-290.
18. A private aeronautical research works. Engineer, Vol. 112 (1936), No. 4213, p. 386.
19. H. Pennington. The increasing applications of plastics. Aero Digest, Vol. 29 (1936), pp. 30-31.
20. Aero Research, Ltd. Improving the creep stress of plastics. Aeroplane, Vol. 50 (1936), pp. 231-232.
21. Sidney Ireland. Design for a plastics wing. Aeroplane, Vol. 50 (1936), pp. 345-347.
22. F. R. Shanley. Thin-walled structures. Aviation, Vol. 35 (1936), pp. 29-31.
23. B. Stubblefield. Plastics in aviation. Modern Plastics, Vol. 13 (1936), pp. 17-19.

24. C. C. Walker. The expanding aircraft industry and its possible uses for plastics. Cf. I. Soc. Chem. Ind. (Chem. and Ind. Rev.), Vol. 54 (1935), pp. 1112-1113.
25. G. M. Kline. Organic plastics. Circular of the National Bureau of Standards, C. 411 (1936), pp. 1-7.
26. N. A. de Bruyne, Plastic materials for aircraft construction. J. Roy. Aeron. Soc., Vol. 41 (1937), No. 319, pp. 523-590.
27. K. Riechers. Kunststaoffe im Flugzeugbau. Luftwissen, Vol. 4 (1937), No. 8, pp. 235-242.
28. Plastic airscrew blades. Aeroplane, Vol. 53 (1937), No. 1364, p. 61.
29. G. M. Kline. Plastics as structural materials for aircraft. N.A.C.A., T.N. 628 (1937).
30. Towards thermoplastics. Flight, Vol. 32 (1937), No. 1491, p. 100.
31. Towards an ideal (Jicwood, Jicglue). Aeroplane, Vol. 53 (1937), No. 1371, pp. 431-432.
32. A. S. T. Thomson, R. Livingstone. Creep in strip and ring specimens of bonded fabric material. J. Roy. Tech. Coll., Glas., Vol. 4 (1938), pp. 376-383.
33. N. A. de Bruyne. Synthetic materials for aircraft construction. Aeroplane, Vol. 52 (1937), pp. 142-145.
34. E. P. King. Discussion of de Bruyne's paper. Aeroplane, Vol. 52 (1937), pp. 195-197.
35. A. F. C. Boys. Possibilities for plastics. Aeroplane, Vol. 52 (1937), p. 598.
36. F. R. Shanley. Criteria of structural efficiency. Aeroplane, Vol. 52 (1937), p. 654.
37. Uses for plastics. Aeroplane, Vol. 52 (1937), p. 681.
38. Plastic progress. Aeroplane, Vol. 53 (1937), p. 61.
39. A new wing. Aeroplane, Vol. 53 (1937), pp. 75-76.
40. M. Langley. Plastics in aircraft construction. British Plastics, Vol. 9 (1937), pp. 5-8, pp. 55-58, pp. 185-190.
41. Aero Research, Ltd. Improving the creep stress of plastics. Modern Plastics, Vol. 14 (1937), pp. 44-45.
42. Aero Research, Ltd. New Plastics of aeronautical interest. Modern Plastics, Vol. 14 (1937), p. 42.
43. T. James. Plastics in aircraft construction. Plastics (London), Vol. 1 (1937), pp. 44-47.
44. K. Riechers. Versuche an Kunststoffen fuer den Flugzeugbau. Z. VDI., Vol. 82 (1938), No. 22, pp. 665-671.
45. Kunst- und Presstoffe. 1st and 2nd Sonderheft of VDI., Berlin, 1937.
46. Periodical " Plastische Massen " (1937), November issue.

PHOTOELASTIC ANALYSIS OF THREE-DIMENSIONAL STRESS SYSTEMS USING SCATTERED LIGHT.*

By R. Weller and J. K. Bussey.

Summary.

A method has been developed for making photoelastic analyses of three-dimensional stress systems by utilising the polarisation phenomena associated with the scattering of light. By this method, the maximum shear and the directions of the three principal stresses at any point within a model can be determined, and the two principal stresses at a free-bounding surface can be separately evaluated. Polarised light is projected into the model through a slit so that it illuminates a plane section. The light is continuously analysed along its path by scattering and the state of stress in the illuminated section is obtained. By means of a series of such sections, the entire stress field may be explored. The method was used to analyse the stress system of a simple beam in bending. The results were found to be in good agreement with those expected from elementary theory.

Introduction.

A new method for the photoelastic analysis of three-dimensional (spatial) stress systems was reported in detail at the Eastern Photoelastic Conference at Cornell University in May, 1939. A brief description of the method is outlined in reference 1. Following the announcement of the method, the N.A.C.A. constructed a simple polariscope suitable for preliminary work and began the study of the application of the method to aircraft structures, power plants, and other related problems.

Several investigators have attempted to develop a truly three-dimensional method of photoelastic analysis. With the exception of the fixation method reported in reference 2, these attempts have lacked general usefulness. In the present paper, the basic principles underlying the proposed three-dimensional method are discussed and a concrete example is worked out to show its application.

The Photoelastic Method.

The photoelastic method (references 3, 4 and 5) is based on the fact that many materials, notably certain plastics, become doubly refractive (birefringent) when subjected to stress. The amount of this birefringence may be studied with a polariscope and the characteristics of the stress system obtained. A model of a machine part or of a structural part may therefore be made from such a material and subjected to an appropriate loading system; and the state of stress within it can then be determined. If the materials from which the model and its prototype are made possess similar (proportional) elastic properties, the stress systems will coincide in direction and be proportional in magnitude provided that the deflections are such that the geometry remains substantially undisturbed.

It has been common in the past to study stresses in this manner, but such study has been limited in practice to plane stress systems. Models were cut

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from plates and loaded in a single plane. Many problems have been solved in this manner and valuable data obtained.

Models have been made from glass, celluloid, gelatin, Bakelite, marblette and rubber, but the material known as Bakelite BT-61-893 has been generally accepted as the most suitable for a wide variety of tests. It remains linearly elastic over a wide stress range (0 to 6,000 lb. per sq. in.), its elastic modulus is not too low (600,000 lb. per sq. in.), and its stress-optical coefficient is high (85 lb. per sq. in. per fringe for green light). A discussion of the properties of photoelastic materials is given in reference 6.

Spatial Photoelastic Analysis.

The theory of photoelastic analysis as applied to three-dimensional stress systems will now be considered in some detail. The difficulty in three-dimensional photoelastic analysis by conventional methods has been that, when a beam of light passes through a transparent model in which a spatial stress system exists, the relative retardation observed between the components of the emergent beam is an integrated effect along the total path traversed. No means have hitherto been available for conveniently discovering the way in which the relative retardation takes place along the path.

When light is scattered within a material medium at right angles to the incident beam, the scattered light (reference 7) is plane polarised. This scattering property may be used either as the polariser or the analyser in a polariscope. In Bakelite, this phenomenon is perhaps due to the micelles discussed by Hetényi (reference 2).

In the investigation of the variation in the effect of the birefringence on a light beam as it passes through a model, a source of polarised light within the model capable of motion from point to point might be desirable. In order to produce such a source, an unpolarised beam may be projected into the model and the scattered light may be viewed from a direction 90° to the beam. This arrangement may most conveniently be set up by collimating the beam with a lens and subsequently passing it through a slit, say one-eighth of an inch wide and as long as desired. When this beam is passed through the model, it illuminates a plane section. Viewed along any path normal to the illuminated section, the light appears plane polarised. If the model is now loaded and an external analyser employed, the birefringence of the material between the illuminated section and the analyser will produce interference effects that vary when either the model or the incident beam is moved about. If a section is illuminated at the surface near the observer and moved away from him, the space rate of formation of fringes, dN/ds, is a measure of the birefringence in successive planes normal to the observation direction. Here N is the number of cycles of interference observed along the path and s is the path variable.

Owing to the complications involved in accurately measuring the movement of the light beam, another method of surveying the model is recommended. Let a *plane polarised* beam be projected into the model through a slit as previously described. The scattering process in the model then acts as the analyser rather than as the polariser and no external analyser is required. The value of dN/ds is now a measure of the birefringence in successive planes normal to the incident light beam.

The relations between the birefringence and the stresses at any point in a loaded model may be considered as follows. When a material (such as Bakelite) becomes optically anisotropic, its optical properties at a given point may be conveniently described in terms of three principal indices of refraction, n_1, n_2, and n_3. These indices always lie at right angles to each other in space. If the optical anisotropy is due to stress, the three principal indices will lie in the direction of the three principal stresses (S_1, S_2, and S_3). Furthermore, the

departures of the three indices n_1, n_2, and n_3 , from the unstressed value n_o are proportional to S_1, S_2, and S_3; that is,

$$K(n_o - n_1) = S_1$$
$$K(n_o - n_2) = S_2$$
$$K(n_o - n_3) = S_3$$

where K is a constant characteristic of the material. In another form,

$$K(n_2 - n_1) = S_1 - S_2$$
$$K(n_3 - n_2) = S_2 - S_3$$
$$K(n_1 - n_3) = S_3 - S_1$$

If $S_1 < S_2 < S_3$, the maximum shear is given by

$$\tau_{max} = (K/2)(n_1 - n_3)$$

The maximum shear at a point may then be found by measuring $n_1 - n_3$ at the point, provided that K is known.

If a beam of polarised light passes through the point in question along the direction of S_2 and is polarised at 45° to S_1 and S_3, the relative velocity of its components will depend on the ratio of n_1 to n_3. Relative retardation will take place between the components at a rate given by

$$dR = (n_1 - n_3)\, ds$$

or, expressing the relative retardation in wave lengths,

$$dN/ds = (1/\lambda)(n_1 - n_3) = (1/K\lambda)(S_3 - S_1) = (1/C)(S_3 - S_1)$$

where λ is the wave length in air of the light used, N is the amount of the relative retardation in wave lengths (cycles of interference), and C is another constant called the stress-optical coefficient of the material. Inasmuch as it is proposed to analyse the light continuously along its path by scattering, a fringe will appear each time the relative retardation equals a whole number of wave lengths; that is, when

$$R = N\lambda \quad (N = 1,\ 2,\ 3,\ \ldots\ m).$$

If the direction of S_2 is unknown, the beam of light may be passed through the point in various directions until dN/ds is a maximum; that is, until the fringes appear most closely spaced. The light beam is then travelling along the direction of S_2. If it is assumed that the stresses remain sensibly constant over a small increment of light path, the formula may be written as

$$S_3 - S_1 = C(\Delta N/\Delta s).$$

If the increment is such that $\Delta \mathbf{N} = 1$, then Δs is the fringe spacing and hence measurement of Δs determines $(S_3 - S_1)$. If Δs is referred to as d, then

$$S_3 - S_1 = C/d$$

Certain phases of the fringe formation process will now be considered. The scattered light is considered to be due to the vibration of submicroscopic particles in the scattering medium. These particles vibrate in the direction of the electric vector of the incident beam of light. In birefringent material, such a particle vibrates under the influence of each of the two components into which the light divides. Light being a transverse wave motion, only the component of vibration normal to the direction of observation yields visible light. Hence, the vibrating particle should be viewed from a direction such that both light components take part in forcing the vibration. Interference between components will then be visible. If the light beam travels along S_2 and the observer looks along S_1 or S_3, no interference effects will be visible, but if the observer looks along a direction 45° to S_1 and S_3, fringes with maximum visibility will be seen. The positions of minimum fringe intensity give the directions of S_1 and S_3.

As a simple example of this procedure, consider the case of a tension member of rectangular cross section. Let a beam of light be collimated, planepolarised, and projected into such a model through a slit. Let the slit lie parallel to the stress direction so that the illuminated section is a longitudinal one through the piece. Let the light be polarised in a direction at 45° to the direction of the

stress. If the model is observed from a direction either parallel to or normal to the direction of polarisation and at 90° to the incident light direction, fringes will appear which are equally spaced. Hence dN/ds is a constant, and therefore the birefringence is constant along the light paths. The result then indicates that the stress in the model is constant over the cross section. Such a fringe pattern is shown in Fig. 1. A vector diagram of the light components is shown in Fig. 2. This diagram refers to the point at which light enters the model and before relative retardation has taken place between its components. Observation along A corresponds to the case in the plane-stress polariscope in which the polarising units are set for a dark field and, along B, to the case of a light field.

The principal stresses at a free boundary may be individually measured since the stress perpendicular to such a boundary vanishes and the other two stresses lie in the tangent plane. If the direction of the light is made parallel to this tangent plane, the model may be rotated about a point in the tangent plane until the maximum and the minimum fringe spacings are obtained. These spacings will give the separate principal stress values.

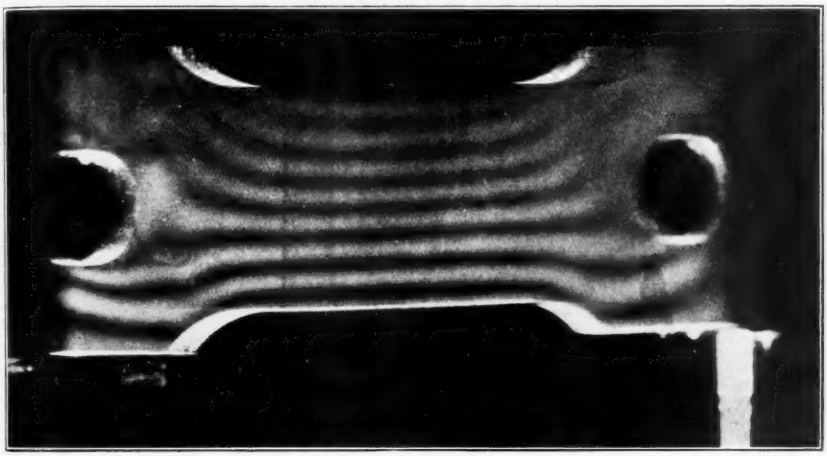


FIG. 1.
Fringe pattern in tension specimen.

APPARATUS.

The apparatus employed for this study included a polariscope head containing a light source, condensing lenses, a filter, a polarising plate, and a slit. Above the head was placed a glass tank filled with a suitable liquid in which the models were immersed. A camera was provided for photographic recording. The arrangement of these elements is shown in Figs. 3 to 5.

The light source for these studies must be intense and a type H-6 Westinghouse 1,000-watt mercury arc lamp of the water-jacketed variety was obtained. This lamp has been very satisfactory as regards intensity. Its spectrum, however, contains many more lines than the ordinary mercury arc and apparently has a fairly intense continuous background, so that difficulty was experienced at first in obtaining a monochromatic beam. Such a beam is highly desirable to prevent overlapping of various colours at high orders of interference. The combination of a Wratten No. 77 filter with a Wratten B filter seemed best for photographic recording and the Wratten No. 77 alone for visual observation. The problem is further complicated by the variation in monochromatic scattering

power for Bakelite, which is apparently strongest in the blue region, as would be expected. The lamp requires a separate transformer operating on 110 volts alternating current and a water supply of about one gallon per minute. Provision for automatic shut-off of the power supply in the event of water supply failure was not provided, although the automatic feature is very desirable.

Two condensing lenses 6.5 inches in diameter served to collimate the light beam, the lamp being placed at the focal point of the combination. The approximate speed of the condensing lens system was f : 0.83.

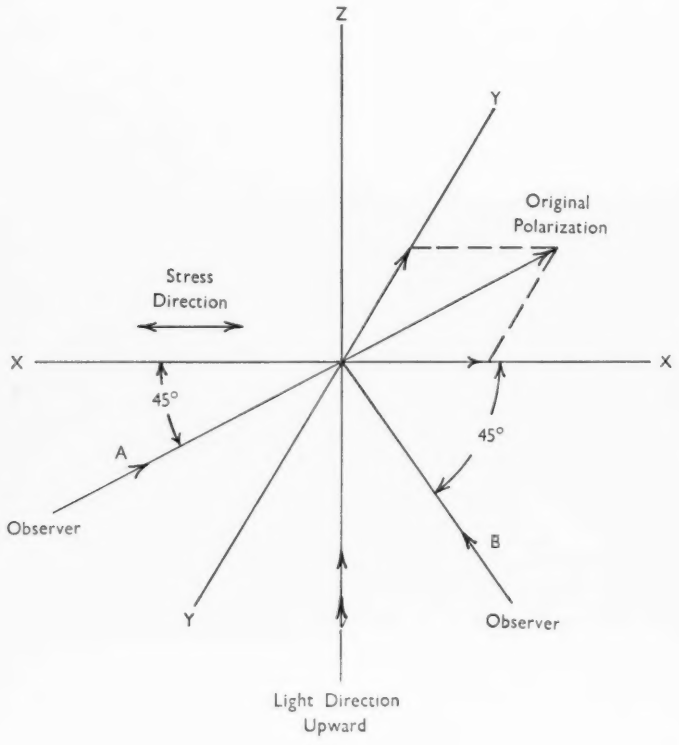


FIG. 2.
Vector diagram for tension.

The polariser employed was a sheet of type I Polaroid. No quarter-wave plate was used during the tests to be described, but one may occasionally be necessary to project circularly or elliptically polarised light into the model.

The slit was approximately one-tenth inch wide and equal in length to the diameter of the collimated beam. Naturally, the intensity of the fringes and the speed of photographic recording vary directly with the slit width. The width used resulted in fringes easily visible in daylight. The exposures were of the order of one minute with the filter combination mentioned and a high speed film. On the other hand, the slit width effectively determines the gauge length over which the measurements are made; hence, it should be as narrow as possible consistent with satisfactory visibility and photographic exposure. Good visibility was obtained with the slit width greatly reduced, probably to about 0.01 inch.

In order to avoid refraction at model surfaces, the model must be immersed in a clear liquid having the same refractive index ($n = 1.57$) as Bakelite. A mixture of the following proportions (by volume):—

Halowax oil No. 1,000 ($n = 1.63$)	66 per cent.
Clear mineral oil ($n = 1.43$)	34 per cent.

was found to give the correct refractive index. This liquid was contained in a glass wall tank 8 inches by 8 inches by 6 inches deep, made of plate glass united with Sauereisen cement.

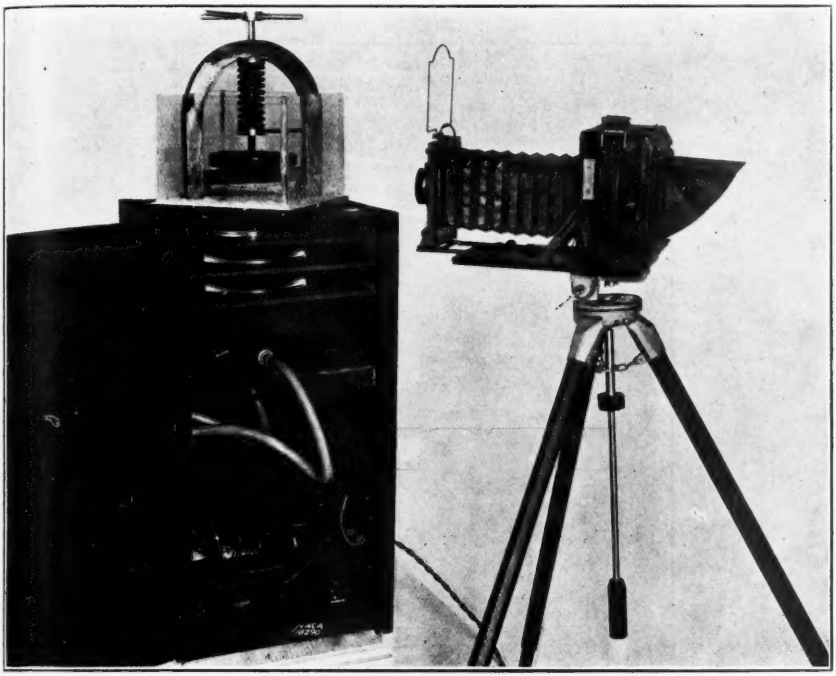


FIG. 3.
General view of apparatus showing location of polariscope, tank, model, and camera.

EXPERIMENTAL PROCEDURE.

A beam in uniform bending was selected as an example of the method. The stresses under a given loading were photoelastically measured and were subsequently checked by calculation according to the elementary theory. Two beams were cut from a block of Bakelite BT-61-893. No annealing was attempted. The models were 0.75 inch by 0.75 inch in cross section and were six inches in length. They were loaded in a small fixture constructed for the purpose. Figs. 6 and 7 show a beam in place. Loads were found by measuring the deflection of the spring contained in the fixture.

One beam was cut from the Bakelite block along an edge exposed during the "curing" process. This beam showed the prominent initial stress pattern seen in Fig. 8 (*a*). In Figs. 8 (*b*) and 8 (*c*) are shown the fringe patterns in this beam due to one-half load and full load in bending. It will be noted that the

distortion of the pattern from symmetry about the neutral axis decreases with increasing load, that is, the relative influence of the initial stresses decreases.

Fig. 9 shows the bending pattern of the second beam, which was cut from the parent material in such a way as to be well removed from previously exposed surfaces. This pattern shows satisfactory symmetry and was taken as the basis for comparison with theory. Table I shows the values obtained. The procedure in obtaining the data was as follows:—The negative of Fig. 9 was placed on the stage of a micrometer comparator and traverses were made along a vertical line at the centre of the beam. Positions of the dark fringes are recorded in the first column of Table I. Inasmuch as the image on the negative was reduced

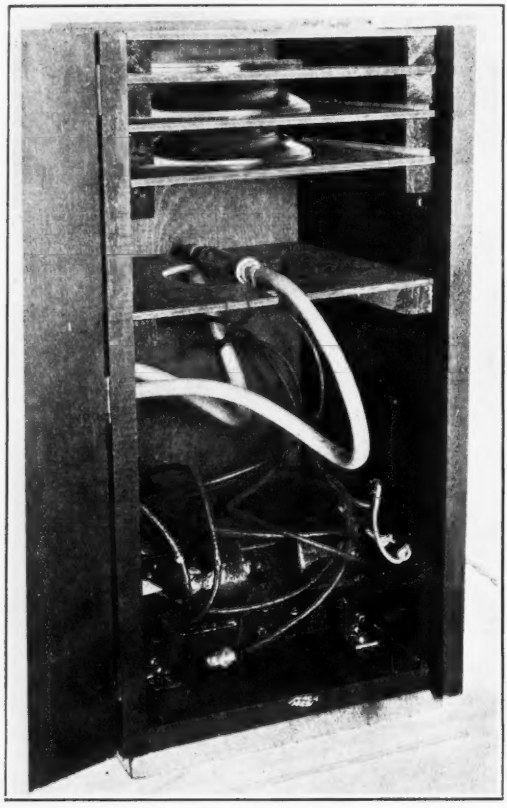


FIG. 4.
Internal layout of polariscope.

in size as compared with the beam itself, the readings were multiplied by a factor (1.93) after subtraction from the initial reading as shown in the second column. The second column then gives the displacement of the fringes from the edge of the beam through which the light entered. The stress value obtained from the spacing between a given pair of fringes was assumed to correspond to a point midway between them. The third column gives the location of these points. The actual spacing of the fringes is shown in the fourth column. In the last

column are recorded the stresses obtained by dividing the fringe value of 85 pounds per square inch per fringe by the spacing.

TABLE 1.

DATA ON CROSS SECTION OF BAKELITE BT-61-893 BEAM, CORRECTLY CUT.

Position of dark fringes on negative (in.)	Position of fringes in model (in.)	Stress location (in.)	Fringe spacing (in.)	Stress values (lbs./sq. in.)
0.524	0			
		0.010	0.019	4,500
0.534	0.019			
		0.032	0.027	3,150
0.548	0.046			
		0.060	0.027	3,150
0.562	0.073			
		0.089	0.031	2,750
0.578	0.104			
		0.122	0.037	2,300
0.597	0.141			
		0.162	0.042	2,000
0.619	0.183			
		0.206	0.049	1,750
0.644	0.232			
		0.277	0.090	950
0.691	0.322			
	Centre line of model.			
0.758	0.452			
		0.488	0.073	1,150
0.796	0.525			
		0.550	0.050	1,700
0.822	0.575			
		0.595	0.041	2,050
0.843	0.616			
		0.632	0.032	2,650
0.860	0.648			
		0.662	0.028	3,050
0.874	0.676			
		0.690	0.028	3,050
0.890	0.704			
		0.718	0.029	2,950
0.904	0.733			
edge 0.912	0.749			

The neutral axis of the beam (centre line of the model) represents a barrier across which fringe-spacing measurements cannot be made. Such a measurement would give the spacing of a fringe with respect to itself and such a measurement has no meaning. The spacing across a region in which a reversal from tension to compression, or vice versa, takes place, bears no relation to the stress but depends rather on the relative phase of the light components as they cross the neutral section. Only when this phase difference is accidentally zero, will the measurement be significant in terms of stress.

The values from Table I are plotted in Fig. 10. Inasmuch as this type of stress distribution is a straight line to a good approximation, such a line was drawn through the points. Calculation using the applied load of 350 pounds and moment arms of 1.37 inches gives

$$\sigma = M/Z = (175 \times 1.37 \times 6 \times 64)/27 = 3{,}400 \text{ pounds per square inch}$$

where σ is the maximum stress in the beam, M is the bending moment on the beam, and Z is the section modulus of the beam. This value compares with the value of 3,600 pounds per square inch given by the intersection of the plotted value line with the model edges. The discrepancy here is 5.5 per cent. of the computed value. The average deviation of the significant points from the curve is 4 per cent.

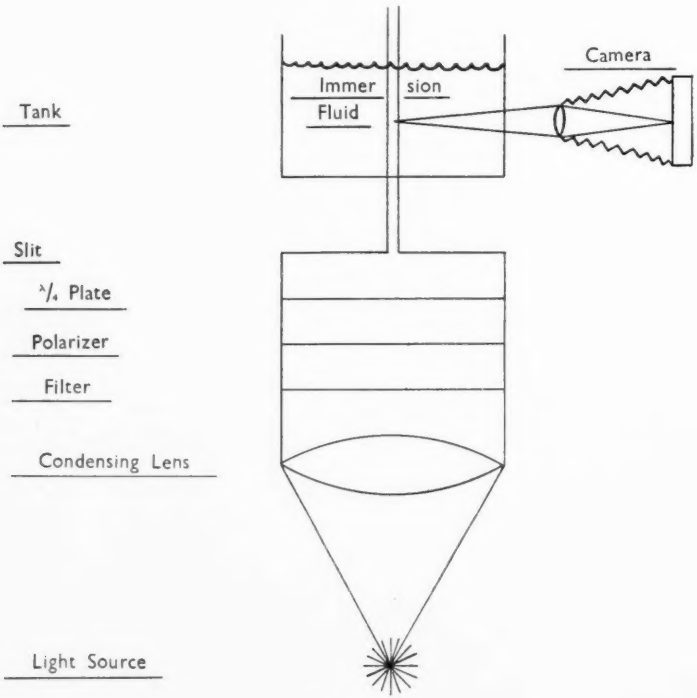


FIG. 5.
Schematic diagram of polariscope.

As some of the equipment used was incapable of precise measurement, the result is considered good agreement. Sources of error may have been:—

(1) Error in model dimensions.
(2) Error in spring calibration.
(3) Error in spring-deflection measurement.
(4) Error in measuring roller positions on beam.
(5) Friction in loading fixture.
(6) Error due to deflection of beam.
(7) Errors due to photographic distortion.
(8) Errors in centring fringe line in micrometer comparator.

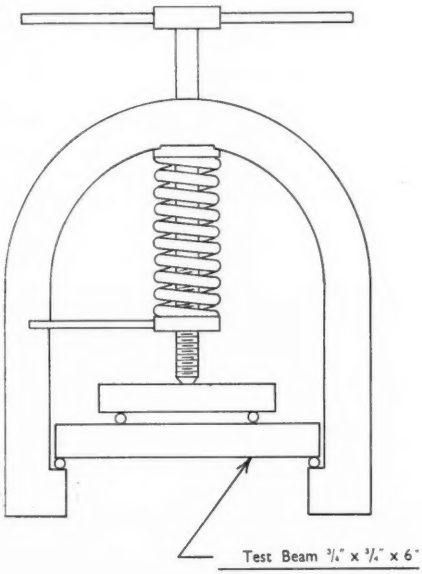


FIG. 6.
Loading fixture.

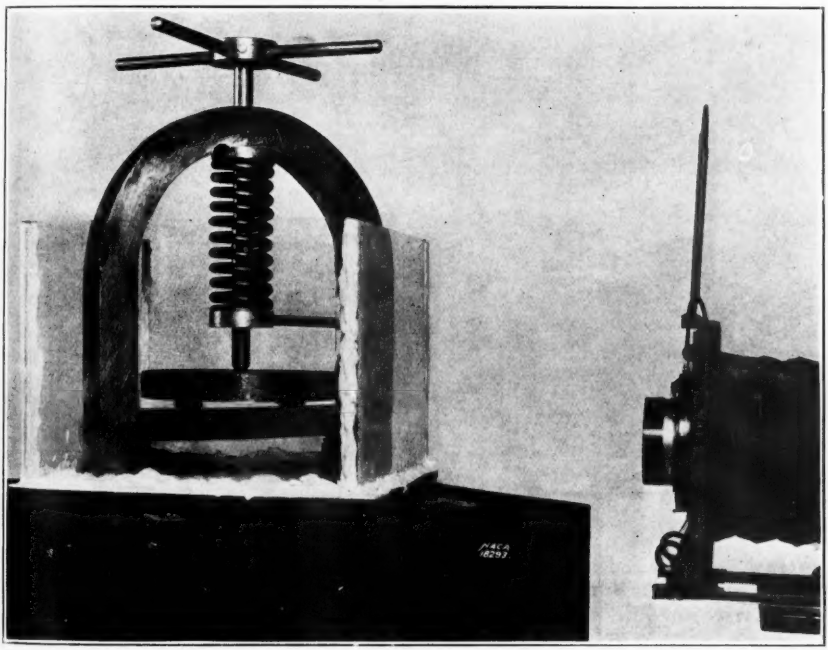
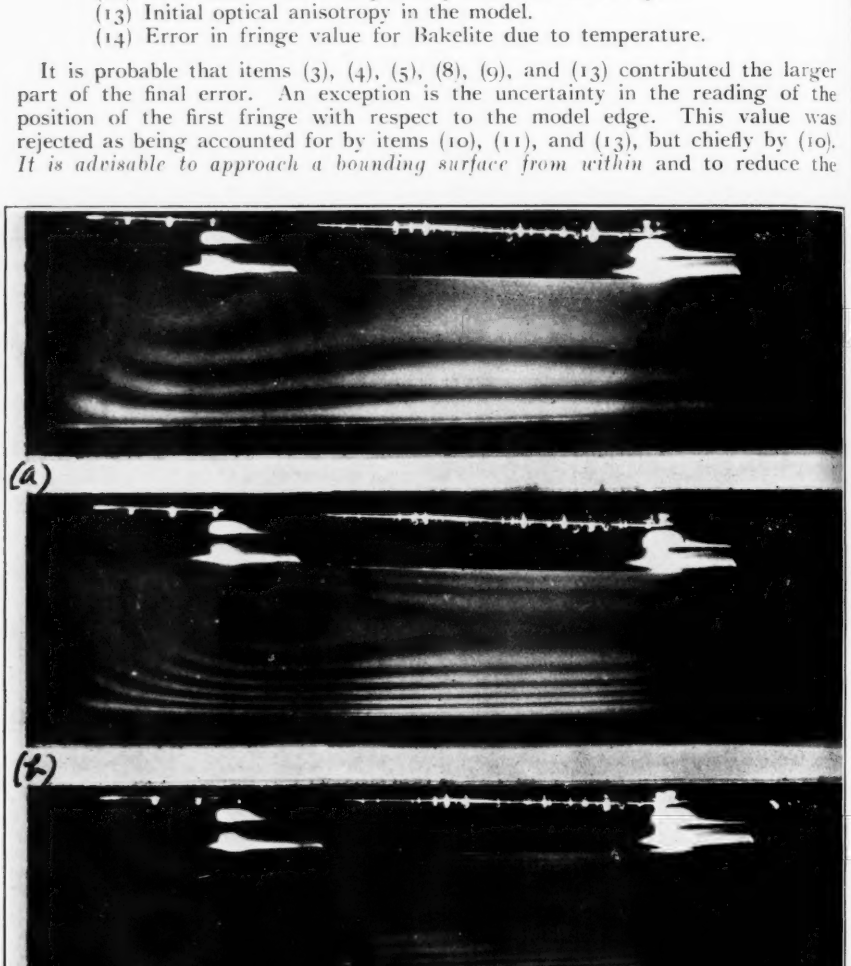


FIG. 7.
Loading fixture with model in place.

(9) Error due to proximity of load points.
(10) Error due to strains in tank bottom.
(11) Error due to strains in Polaroid disc.
(12) Error due to lack of perfectly monochromatic light.
(13) Initial optical anisotropy in the model.
(14) Error in fringe value for Bakelite due to temperature.

It is probable that items (3), (4), (5), (8), (9), and (13) contributed the larger part of the final error. An exception is the uncertainty in the reading of the position of the first fringe with respect to the model edge. This value was rejected as being accounted for by items (10), (11), and (13), but chiefly by (10). *It is advisable to approach a bounding surface from within* and to reduce the



(*a*) *Initial stress pattern* (*no load*).
(*b*) *Half bending load.*
(*c*) *Full bending load.*

FIG. 8.

Stress pattern in a Bakelite beam showing initial stress resulting from an edge that has been exposed during curing.

effect of these items by plotting a curve such as has been done here. Items (10) and (11) can affect only the position of the first fringe.

In general, it may be said that the errors listed in items (1) through (9) are not characteristic of this method of stress analysis and may be controlled by well-known methods. Errors due to (10), (11), and (12) can be eliminated without difficulty by the use of well-designed equipment. Item (13) is controllable by suitable choice of model material; by careful machining; and by testing the model soon after cutting; or, when such testing is inconvenient, by measuring the initial conditions without load and subtracting the result from later readings. The variation due to item (14) is small because of the manufacturer's care in processing (reference 6).

An additional possible source of error is due to the assumption that the stress computed by the spacing of two adjacent fringes exists at a point midway between them. This assumption is more nearly true as the spacing of fringes becomes more uniform with high loads. In the present example, the departure of the representative point from the midway position could have been computed, but computation is generally impossible. Here, as in plane photoelastic analysis, a high fringe order is conducive to precise results.

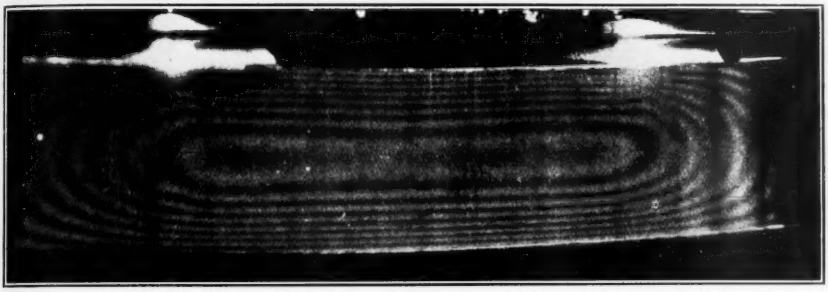


FIG. 9.

Bending stress pattern in correctly cut beam.

As an example of the usefulness of the method in a slightly more complex problem, the variation in the stress pattern due to a vertical hole through the centre of a beam is presented. A hole of $\frac{5}{16}$-inch diameter was drilled through the centre of the beam previously analysed. Figs. 11 and 12 show the stress patterns in the central plane and in face of the beam, respectively.

The disturbance in the fringe pattern at the load points was insignificant for both beams tested. This result is in contrast to the prominent effects obtained in the usual plane-stress pattern. In the three-dimensional method, the components of stress that lie in horizontal planes are effective and no vertical stress components influence the fringe positions. If the model had been illuminated by a horizontal beam, the resulting fringes would have indicated the effect of the concentrations very prominently. The operator must not expect to see the types of fringe patterns that have come to be associated with photoelastic methods in the past because the present procedure involves a new type of stress-optical behaviour.

CONCLUDING REMARKS.

The foregoing results indicate that the method developed for three-dimensional photoelastic stress analysis is sound, that the apparatus described is suitable for a wide variety of stress investigations, and that the experimental techniques employed yielded satisfactory results. This method appears to be a substantial

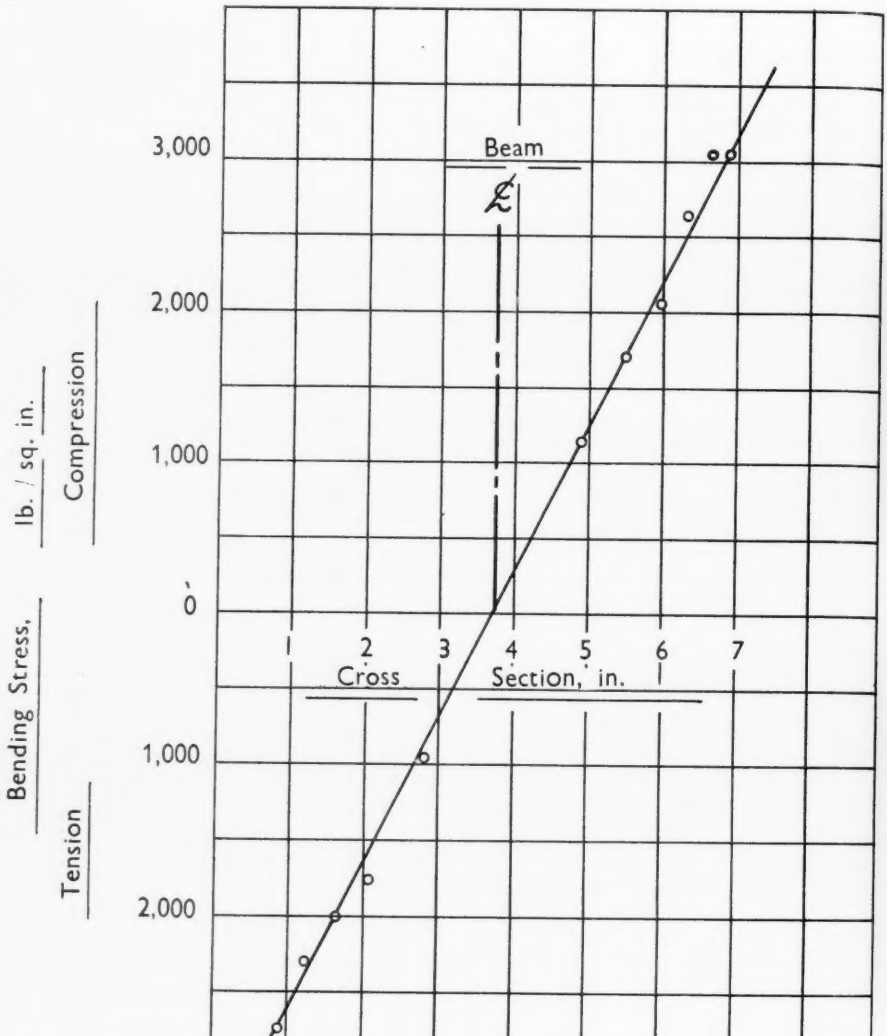


FIG. 10.

Beam stress plotted from values in Table I.

improvement over previous attempts to solve spatial stress problems by the use of photoelastic models and, in a large number of cases, appears to be the only method thus far developed that will provide a solution in a convenient manner.

In the solution of the case of the beam in simple bending, as analysed by the method outlined in the paper, the agreement with accepted beam theory was within 5·5 per cent. No basic assumptions are made in developing the theory other than those already well established in plane photoelastic procedure.

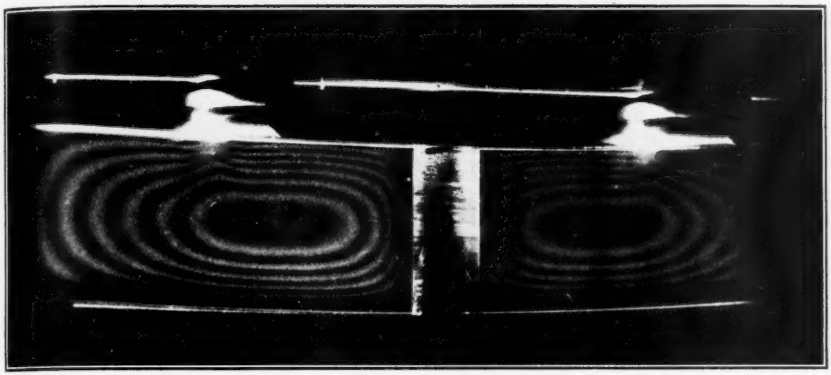


FIG. 11.

Beam with vertical hole, centre section stress pattern.

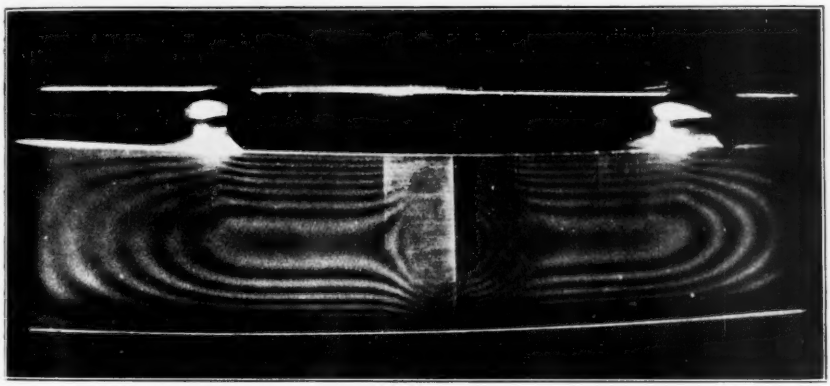


FIG. 12.

Beam with vertical hole, edge section stress pattern.

Persons should familiarise themselves with the elementary phenomena associated with the scattering of light before attempting experiments by this method.

It may at times be desirable to submit to some of the disadvantages of the fixation method and, having " frozen " a stress system into a model, to examine it by the methods described in this paper. The tension model used in this investigation was so treated.

The principal stresses at a free boundary may be individually measured since the stress perpendicular to such a boundary vanishes and the other two stresses

lie in the tangent plane. If the direction of the light is made parallel to this tangent plane, the model may be rotated about a point in the tangent plane until the maximum and the minimum fringe spacings are obtained. These spacings will give the separate principal stress values.

Many problems suggest themselves as suitable subjects for investigation. Certainly stress concentrations in three-dimensional systems should be thoroughly explored, particularly in connection with torsional stresses. It also seems possible that some of the problems which have been treated as two-dimensional ones in the past may not in fact be two-dimensional and that more accurate results could be obtained by the suggested method.

REFERENCES.

1. Weller, R. : "A New Method for Photoelasticity in Three Dimensions." Jour. Appl. Phys., Vol. 10, No. 4, April, 1939, p. 266.
2. Hetényi, M. : " The Fundamentals of Three-Dimensional Photoelasticity." Jour. Appl. Mech., Vol. 5, No. 4, December, 1938, pp. A-149—A-155.
3. Coker, E. G., and Filon, L. N. G. : " A Treatise on Photoelasticity." Cambridge Univ. Press, 1931.
4. Riggs, Norman C., and Frocht, Max M. : " Strength of Materials." The Ronald Press Co., 1938, ch. 13.
5. Mindlin, Raymond A. : " A Review of the Photoelastic Method of Stress Analysis." Jour. Appl. Phys., Vol. 10, No. 4, April, 1939, pp. 222-241, and Vol. 10, No. 5, May, 1939, pp. 273-294.
6. Lee, G. H., and Armstrong, C. W. : " Effect of Temperature on Physical and Optical Properties of Photoelastic Materials." Jour. Appl. Mech., Vol. 5, No. 1, March, 1938, pp. A-11—A-12.
7. Wood, Robert W. : " Physical Optics." The Macmillan Co., 1919, ch. XXII.

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(*Prepared by R.T.P.*)

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Investigations on Bomb Trajectories—Effect of Changes in Ballistic Coefficient Altitude, Angle and Velocity at Release on the Horizontal Trajectory (Range). (D. Borsani, L'Aerotecnica, Vol. 19, No. 6, June, 1939, pp. 678-684.) (73/1 Italy.)

Starting with the well known Siacci type of solution for the external ballistic problem, the author obtains a difference formula connecting Δx, Δy, $\Delta\phi$, ΔC^1, and ΔV, where

x = range.
y = altitude at release.
ϕ = angle of tangent to trajectory with horizon at release.
C^1 = " reduced " ballistic coefficient of bomb.
V = velocity at release.

From this formula, four factors (C_H, C_φ, C_{C^1} and C_V) are deduced which give respectively the percentage variation in range due to 1 per cent. change in altitude, ballistic coefficient and launching speed and due to a 1° change in ϕ.

The case of a 250 kg. bomb (ballistic coefficient 1.75, form coefficient 1) launched horizontally ($\phi=0$) at 120 m./sec. at various altitudes ranging from 1,000 to 5,000 m. is next considered. Over this range of height

C_H = approximately constant and = 0.46.
C_φ varies from 1.4 (at 1,000 m.) to 0.6 (5,000 m.).
C_{C^1} varies from 0.03 to 0.11.
C_V varies from 0.7 to 1.2.

From this it appears that in the case of horizontal bombing, a 1 per cent. change in launching speed gives approximately a 1 per cent. change in range. A 1 per cent. change in altitude at release gives approximately a ½ per cent. change in range. A 1° error in horizontality at release gives 1.1 per cent. change in range. A 1 per cent. change in ballistic coefficient is negligible as regards range. A correct estimation of the launching angle is thus of the greatest importance, especially at low altitudes.

The factors C_H, C_φ, etc., developed above only apply for small changes in the characteristic values, they obviously cannot be applied to convert horizontal into dive-bombing data.

Such trajectories have to be calculated afresh, and this presents no great difficulty using the Siacci Method. Once the elements of such a trajectory are known, the effect of subsequent small changes in the characteristics can be

determined with the help of the C factors obtained above. Thus, in the case of dive bombing

$$C\phi = \{ 1.745 \cos (2\phi - \epsilon) \} / \{ \cos^2 \phi \cos \epsilon \tan w \}$$

where ϕ = angle of release.
w = angle of impact.
$\epsilon = \tan^{-1} y/x$.

The actual calculation is not carried out in the present paper, but the author hopes to return to the subject in a further issue.

ABSTRACTOR'S NOTE.—Similar difference formulæ to those developed by the author are given by Cranz " Lehrbuch der Ballistik," Vol. 1, p. 284. Complete tables for the Siacci solution are also given in an appendix to this volume.

Motor Fuel Supply for the French Air Force. (Flemmig, W. T. M., Vol. 43, No. 10, October, 1939, pp. 414-6.) (73/2 France.)

To assist the fuel requirements of the French Air Force it is proposed to erect four hydrogenation plants having a total yearly output of 230,000 tons of high octane aviation spirit. Two of them, of capacity 100,000 tons and 70,000 tons respectively are to be erected on the Atlantic coast and will employ fuel and gas oils exclusively as raw materials. The third plant, of 30,000 tons output to be erected on the Mediterranean coast, will also treat fuel and gas oils, but provision is to be made for treatment of brown coal if necessary. The fourth, of similar capacity, will be situated in the centre of France and is to employ bituminous coal as raw material.

The plan is not yet finally settled on account of the enormous costs of the plant. The present two experimental plants at Liévin and Bethune, each of 5,000 tons annual output, have together cost about 180 million francs, at the present rate of currency, and the cost of producing synthetic petrol is eight to ten times the import price.

Bombardment of the Battle Field. (Rev. de l'Arm. de l'Air, No. 118, Sept.-Oct., 1939, pp. 574-5.) (73/3 Japan.)

A Russian account is given of the technique employed by the Japanese in bombing battlefields. Individual dive bombing attack is carried out as follows:—

The aeroplane approaches obliquely at about 800-1,000 m., for easy observation, then turns sharply through 30-40° and dives on the objective at an angle of 60-70° down to an altitude of 400 m. The velocity which was originally of the order of 140 km./kr., increases to 300-340 km./kr. with the ordinary aircraft in use. The manœuvre is completed by escaping in a turn to left or right. When the bombardment is carried out by a patrol, the latter commences to perform curves at a distance of 10-12 km. from the object, at an initial altitude of 3,000-5,000 m., decreasing progressively to 1,200-1,500 m.; this is the period during which the objective is observed. Horizontal flight is then maintained during 10-15 sec., in order to get into position, and speed is reduced. At a signal from the patrol leader the machine dives and escapes by a turn.

The bombs employed for dive bombing are generally 100 kg. According to the Japanese, the methods employed by them have the advantages of simplicity of execution without specialised observers, precision in aiming and small vulnerability from A.A. fire.

The Military Importance of the Stereoautomatic Device for Evaluating Films of Anti-Aircraft Target Practice. (H. Brandli, Flugwehr und Technik, Vol. 1, No. 8, August, 1939, pp. 217-219.) (73/4 Switzerland.)

The shell bursts near a towed target are recorded simultaneously on two Askania cine theodolites placed at the ends of a known base. The stereoautomatic device enables the co-ordinates of the shell burst relative to the target

as well as the resultant distance of the explosion to be obtained very quickly. Thus the total time required to measure up ten bursts is of the order of eight minutes, including the developing of the film. It is thus possible for the gun crew to judge the accuracy of each shot whilst the circumstances of the firing are still fresh in their minds.

A direct comparison between the relative accuracy of manual gun control and that given by the " gamma " predictor gear is of interest. It appears that the " placing " of the shell burst by a single observer is very difficult and that in many cases the automatic predictor gear gives the better results.

The author is of the opinion that apart from training the rapid evaluation of firing films will be most useful in maintaining the high standard required by A.A. batteries in war time.

Main Considerations for the Selection of Military Pilots. (H. Meier-Muller, Flugwehrund Technik, Vol. 1, No. 8, August, 1939, pp. 221-223.) (73/5 Switzerland.)

According to the author, 70-80 per cent of all flying accidents are due to errors of judgment of the pilot.

It is thus essential that the mental make-up of the pilot be such that quick decisions come to him naturally. Mental alertness, on the other hand, depends largely on physical conditions and the health of the pilot, *i.e.*, his ability to withstand the physical strain of modern high speed flying is thus of great importance.

Over and above these requirements, the military pilot must be amenable to discipline, courageous, and ready for any sacrifice.

The organic health and resistance to special flight conditions (acceleration, cold, lack of oxygen, etc.) of the candidate are tested relatively easily. Mental alertness and general psychological qualities as well as character and general suitability for leadership are factors which cannot be expressed numerically, and although most of the modern air forces have devised psychological tests, the results are only of value if interpreted by men of large experience.

It appears that the main difficulty is the youth of the military pilot. Speaking psychologically, the applicant is immature and undergoing rapid development. As a result a judgment in mental make-up may require subsequent revision.

Petroleum for Germany at War. (B. T. Brooks, Ind. and Eng. Chem. (News Ed.), Vol. 17, No. 21, 10/11/39, pp. 679-680.) (73/6 Germany.)

If Germany is able to secure the whole of Russia's exportable surplus of petroleum and a similar amount from Rumania she will have sufficient war supplies without drawing on the reserve of 35-40,000,000 barrels, which has been accumulated since 1934.

Germany's war requirements are estimated to be about 75,000,000 barrels per annum. Without Russian and Rumanian assistance she will be able to raise only about one-third of this quantity. No accurate figures are available for production of oil from coal.

As regards aviation fuel, production of high octane fuels is a matter of difficulty. The product from the Fischer-Tropsch process has a very low octane rating and it has to be cracked or reformed to produce good quality motor spirit. The Bergius product, however, has an octane rating of about 70 and the method of reforming naphthas by catalytic hydrogenation can give a product of 80-82 octane value without addition of lead.

About 20 per cent. of the German Air Force is estimated to operate on Diesel power. An unknown number of machines have been modified for using benzene blends, thus enabling them to use 4,500,000 barrels of benzene for aviation purposes. Fuel injection in place of a carburettor also allows a wider range of petrols to be used for aviation purposes.

Glass for A.R.P. Purposes. (Engineering, Vol. 148, No. 3,855, 1/12/39, p. 618.) (73/7 Great Britain.)

Some forms of glass offer considerable resistance to blast, the resistance of armour plate glass being five of six times that of ordinary polished plate glass of the same thickness. When shattered it breaks in small pieces which are neither large enough nor sharp enough to cause injury. Protection against splinters, though not against bullets, is afforded by $\frac{3}{16}$ in. Triplex-Armourplate, consisting of three layers of armourplate glass with intermediate layers of cellulose acetate. Toughened glass lenses when set in concrete will resist the blast from a 500 lb. high explosive bomb at a distance of 50 feet. The same lenses used in concrete roofs will also withstand the action of incendiary bombs. Vitrolite is suitable for the walls of decontamination chambers because it is non-absorbent and easily washed down.

Detonation of High Explosives in Shell and Bomb and its Effects. (D. D. Logan, British Medical Journal, No. 4,111, 21/10/39, pp. 816-819.) (73/8 Great Britain.)

Quite apart from the direct effect of concussion and splinters, the detonation of high explosives gives rise to large quantities of gas, the CO content of which increases rapidly if the detonation is imperfect. In confined spaces, therefore, casualties may arise due to gas poisoning, the ordinary gas mask affording no protection against CO. But quite apart from their poisonous nature, the gases liberated may form explosive mixtures with the air and in confined spaces (cellars, basements) there is a danger of a possible explosion which may persist for hours after the bombardment. It is therefore essential that only electric torches be used when examining cellars after a raid.

Organisation and Treatment of Air Raid Casualties. (J. Trueta, British Medical Journal, No. 4112, 28/10/39, 877-879.) (73/9 Spain.)

The principal recommendation of this Spanish surgeon (director of the department of surgery of one of the principal hospitals of Barcelona during the Civil War) is that all first aid posts separate from hospitals should be abandoned, as they delayed treatment and increased mortality. More than 30 per cent. of the patients needed operations and rapid admission to hospitals was their only chance; good organisation to ensure rapid transport to the hospital is essential. Arrived there, the patients are rapidly classified into five groups —

(i) Cases for immediate operation and could not be evacuated after treatment.
(ii) Immediate operation and subsequent evacuation.
(iii) Immediate non-operative treatment and no evacuation.
(iv) First aid followed by evacuation to base.
(v) First aid and sent home.

The lecturer made special reference to the type of injuries inflicted by small splinter bombs. These splinters travel mainly in a horizontal direction and are so small that the skin lesion is painless and without hæmorrhage. The internal damage done is, however, very considerable. Owing to the fact that many civilians had been recommended to lie prone during a raid, the splinters were frequently localised in the base of the skull.

On the Sinkage of a Ship at Low Speeds. (T. H. Havelock, Z.A.M.M., Vol. 19, No. 4, August, 1939, pp. 202-206.) (73/10 Great Britain.)

The immersed portion of the ship is assumed to be a semi-ellipsoid, the water surface being the xy plane. Potential flow about this ellipsoid is further assumed, the water surface remaining level. The author next calculates the reduction in the pressure in a vertical direction associated with this flow and deduces the corresponding increase in sinkage.

The results obtained are in agreement as to order of magnitude with those given by the empirical formula of Horn for full-scale ships.

In conclusion the author estimates the increase in the frictional resistance of a model due to sinkage.

On the Velocity Distribution in Turbulent Flow Through a Straight Pipe of Annular Cross Section. (I. Imai and S. Tomotika, Aer. Res. Inst., Tokyo Rept., No. 180, July, 1939.) (73/11 Japan.)

The distribution of mean velocity during the turbulent flow of fluid under pressure through a straight pipe of annular cross section is discussed theoretically on the basis of both the modified vorticity transport and the momentum transport theories of turbulent motion. It is assumed that the turbulence is isotropic and that the mixing length is proportional to the distance from the inner wall in the case of the inner region, whilst in the outer region it is proportional to the distance from the outer wall.

The calculated results are compared with the results of Mikrjukov's recent experiments and it is found that the modified vorticity transport theory gives results in better agreement with observation than does the momentum transport theory for turbulent flow through a straight pipe of annular cross section. A similar conclusion has been reached by Taylor for the case of turbulent flow through a straight circular pipe.

Note on the Effect of the Boundary Walls of a Stream upon the Circulation Round a Plane Aerofoil. (S. Tomotika, K. Tamada and Y. Saito, Aer. Res. Inst., Tokyo Rept., No. 182, August, 1939.) (73/12 Japan.)

The interference effect of the rigid boundaries of a stream upon the circulation round a plane aerofoil is dealt with for the case in which the aerofoil is placed in a semi-infinite stream bounded by a plane wall on the upper or lower side of the aerofoil and between two parallel rigid walls.

In each case it is found that the circulation is greatly affected, particularly when the distance of the aerofoil from the walls is of the order of the chord, or smaller than the chord.

Comparison of the curves for the circulation with the corresponding curves for the lift shows that the alteration in lift of the plain aerofoil due to the walls is mostly caused by the alteration in circulation round the aerofoil.

A critical discussion is made on the applicability of the usual method to the problems of the effect of wall interference on the aerodynamic properties of an aerofoil.

Wind Tunnel Investigation of the Effect of Yaw on Lateral Stability Characteristics, II. Rectangular N.A.C.A. 23012 Wing with a Circular Fuselage and a Fin. (M. J. Bamber and R. O. House, N.A.C.A. Tech. Note, No. 730, Sept., 1939.) (73/13 U.S.A.)

An N.A.C.A. 23012 rectangular wing with rounded tips was tested in combination with a fuselage of circular cross section at several angles of yaw in the N.A.C.A. 7 × 10 ft. wind tunnel. The model was tested as a high-wing, a mid-wing and a low-wing monoplane, each wing position being tested for two values of dihedral and with partial wing span flaps. Specimen graphs of the coefficients of rolling moment C_l', yawing moment C_n' and lateral force C_Y' are given for some of the combinations tested. The rate of change of the coefficients with angle of yaw, ψ', is given for the purpose of stability calculation.

The value of the effect of wing fuselage interference on $dC_l'/d\psi'$ changes sign as the wing moves down from the high to low position with respect to the fuselage, being zero at some intermediate position. In general $dC_l'/d\psi'$ is only slightly affected by wing fuselage interference for a given change in dihedral. Moving the wing from the low to the high position generally tends to increase the values

of $dC_l'/d\psi'$ and $dC_n'/d\psi'$ and to decrease the effectiveness of the fin with respect to $dC_l'/d\psi'$, $dC_n'/d\psi'$ and $dC_Y'/d\psi'$.

Flow Photographs Showing Ground Effect. (H. Muller, Forschung, Vol. 10, No. 5, Sept.-Oct., 1939, pp. 220-6.) (73/14 Germany.)

The ground surface forms a boundary condition in the problem of flow over an obstruction on the ground. In previous model experiments it was customary to reproduce this boundary condition by making the model with an exact counterpart (so-called mirror method), assuming the central plane of the new model to be the plane of symmetry of the flow, and thus acting as a substitute for the ground. However, this is incorrect, since the part of the ground in front of the obstruction gives rise to a friction boundary layer which causes the undisturbed flow to be deflected upwards, while the ground behind the obstruction cuts through the vortex path and neutralises the reciprocal influence of the vortices which detach themselves in pairs above and below, in the case of a duplicate model.

This effect is investigated by means of flow photographs taken both with duplicate models and with a ground plane. For obstacles which move over the ground, similarity between the flow conditions prevailing with a stationary model and with the full-scale object can only be achieved if the ground surface moves at the speed of flow. Pressure distribution measurements on a cylinder show that the critical Reynolds number is reduced by presence of a ground plate in front and bisecting the cylinder.

Different values of the resistance are obtained depending on whether the plate projects both to the front and rear or to the rear only. The latter arrangement gives the smallest resistance in the supercritical range of Reynolds number.

Turbulence, its Cause and Development. (F. Ahlborn, Z. ges. Naturwiss., Vol. 4, 1939, pp. 451-65. Zentralblatt fur Mechanik, Vol. 9, No. 2, 31/10/39, p. 80.) (73/15 Germany.)

The author sets out from the well-known fact that the conditions occurring in the inlet of tubes or channels are essential for formation of turbulence. He has therefore obtained pictures of the flow in a channel with various types of inlet opening. Since in the cases photographed, vortices are formed by a sharp-edged inlet, the author concludes that turbulence will occur at all velocities with this shape of inlet, which is contrary to the experimental evidence of other authors. In his theoretical considerations he also considers the turbulence of flow around bodies and maintains that vortex formation commences at the point of transition from excess pressure to under pressure; this does not agree with the measured results obtained with resistance bodies such as circular cylinders. The author bases his further statements on the assertion that the picture of turbulence is different if it gradually develops in wide channels at low velocity, and different again if it suddenly breaks out in full strength in narrow channels at large critical velocities. This statement violates Reynolds law of similarity, which can be regarded as fully confirmed, at least at sufficient distance from the inlet, at which the turbulent resistance laws were determined.

The Problem of the Longitudinal Motion of Aircraft Under the Action of Gravity Only. (W. Muller, Z.A.M.M., Vol. 19, No. 4, August, 1939, pp. 193-202.) (73/16 Germany.)

The motion of the C.G. of an aircraft in a vertical plane is determined by a system of two equations for the normal and tangential acceleration respectively. Using rectangular co-ordinates, we obtain

$$\ddot{x} = -vk_a(\epsilon\dot{x} + y)$$
$$\ddot{y} = -g - vk_a(\epsilon\dot{y} - x)$$

where k_a = of lift coefficient.
ϵ = mean gliding coefficient
v = velocity along trajectory.

By assuming that $vk = f(t)$, a known function of the time, the complex co-ordinate of the trajectory can be expressed in terms of ϵ and $f(t)$.

Integration is readily possible if $f(t)$ = constant. A diminution of $f(t)$ with time (either hyperbolically or linearly) is also amenable to methods of computation, although the latter case leads to the use of Fresnel integrals.

The author applies his results to the calculation of " loopings," the aircraft having an original $v_0 = 72$ m./sec. in each case, $f(t)$ being either constant or varying with time as discussed above, the value of $f(t)$ at $t = 0$ being however the same for all three loops.

It appears that in the simplified case of no resistance ($\epsilon = 0$) the three loops do not differ markedly except for the trajectory after the cusp, where the linear variation of $f(t)$ gives an appreciably lower trajectory.

In the presence of resistance ($\epsilon = 0.08$) the area of the cusp of the loop diminishes and the trajectory after the cusp is raised.

(For further details of the author's method, see also Ing. Arch., Vol. 9 (1938), p. 258, and Vol. 10 (1939), p. 63.)

The Expression of Certain Integrals Occurring in Wing Vibration Investigations by Means of Cylindrical Functions. (J. Bonder, Z.A.M.M., Vol. 19, No. 4, August, 1939, pp. 251-252.) (73/17 Germany.)

The following four definite integrals are of importance in the Wagner-Glauert theory of non-steady lift of a harmonically vibrating profile in a two-dimensional flow:—

$$\int_0^\infty \{ \sin 2kx/(x+x^2)^{\frac{1}{2}} \}\, dx; \int_0^\infty \{ \cos 2kx/(x+x^2)^{\frac{1}{2}} \}\, dx;$$

$$\int_0^\infty \{ (1+1/x)^{\frac{1}{2}} - 1 \} \sin 2kx\, dx;$$

$$\int_0^\infty \{ (1+1/x)^{\frac{1}{2}} - 1 \} \cos 2kx\, dx.$$

These integrals have been evaluated by Glauert for a few values of the parameter k using the method of series (R. & M. 1242).

Borbely and others have since shown that the integrals can be expressed in a closed form in terms of cylindrical functions. All proofs submitted so far are, however, rather lengthy and complicated.

The author shows that by making the fundamental substitution—

$$2x = \cos t - 1$$

the first two integrals of the above list at once take the form of Bessel and Neumann cylindrical functions of zero order. The remaining two integrals are similarly reducible to Neumann functions with very little extra trouble.

Tests in the Gust Tunnel of a Model of the XBM-1 Aeroplane. (P. Donely and C. C. Shufflebarger, N.A.C.A. Tech. Note No. 731, October, 1939.) (73/18 U.S.A.)

In connection with a general investigation of the loads imposed on aircraft structures by atmospheric gusts, a dynamically scaled model of the biplane XBM-1 has been tested in the gust tunnel with several types of gust.

The tests consisted of flights over the gust tunnel at fixed values of the forward velocity and of the average maximum gust velocity. A minimum of five flights

was made for each of the three gust gradients. Measurements were made of flight velocity, gust velocity, normal acceleration, vertical displacement and pitch.

Good agreement was obtained between the experimental results and the values calculated by means of the theory of unsteady lift of monoplanes for gust gradient distances up to 12 chord lengths. The calculations were based on the assumption that the wings of a biplane act independently in an unsteady flow, and the mean slope of the lift curves of the two wings and the mean chord of the cellule were used in conjunction with data on the unsteady lift of finite wings.

A Simple Method of Obtaining Span Load Distributions. (A. Sherman, N.A.C.A. Tech. Note No. 732, October, 1939.) (73/19 U.S.A.)

The proposed method for determining span load distributions of wings is based on the method of superposition. The first step is to determine a chord distribution which will correspond to an elliptical loading and the given distributions of angle of incidence and the lift-curve slope. The differences between this imaginary chord distribution and the actual one determine the smaller component loads to be added to the initial elliptical loading to produce a new span loading which more nearly satisfies the given problem. This procedure is repeated, but the successive series of additional component loads rapidly become zero.

The method should enable the span load distribution to be obtained by a straightforward arithmetical procedure. Charts have been included to assist in the calculations. It is noted that the interference loads induced at the tips of each additional component load must not be overlooked, and also that the accumulation of computing errors may become serious in problems requiring the addition of many series of component loads. At any stage in the process the accumulation of inaccuracies can be removed by a separate check of the associated induced angle distribution.

Tests in the Variable Density Wind Tunnel of the N.A.C.A. 23012 Aerofoil with Plain and Split Flaps. (I. H. Abbott and H. Greenberg, N.A.C.A. Tech. Rept. No. 661, 1939.) (73/20 U.S.A.)

Aerofoil section data for use in wing design have been determined for the N.A.C.A. 23012 aerofoil with plain and split flaps of 20 per cent. wing chord at an effective Reynolds number of about 8,000,000. The flap deflections covered a range of from 60° upwards to 75° downwards for the plain flap, and from zero to 90° downwards for the split flap. The angle of incidence range extended from below zero lift to beyond maximum lift for all conditions and was extended through negative maximum lift for most of the settings of the plain flap. As applied to this aerofoil section the split flap was superior to the plain flap in producing high maximum lift coefficients, in having slightly lower profile drag coefficients at the lift coefficients used in take-off, and in having smaller pitching moment coefficients for equal maximum lift coefficients Both types were unsatisfactory in producing low profile drag coefficients at the lift coefficients used in take-off as compared with low drag slotted flaps.

Determination of the Profile Drag of an Aeroplane Wing in Flight at High Reynolds Numbers. (J. Bicknell, N.A.C.A. Tech. Report No. 667, 1939.) (73/21 U.S.A.)

Flight tests were made to compare the profile drag coefficient of a portion of the original surface of an all-metal aeroplane with that of a portion of the wing which had been made aerodynamically smooth and more nearly mechanically smooth than the original section. The test panel was sufficiently far removed from the slipstream to avoid interference, and tests were carried out over a range of velocities giving a maximum Reynolds number of 15,000,000. Tests were also made to determine the point of transition from laminar to turbulent boundary layer and to determine the velocity distribution along the upper surface of the

wing. The profile drag coefficients of the original and of the smooth wing portions were 0.0102 and 0.0068 respectively. Manufacturing irregularities in rivets, lap joints, etc., are thus responsible for a 50 per cent. increase in profile drag coefficient. The boundary layer surveys on the upper surface of the smooth wing showed that transition from laminar to turbulent boundary layer occurred at a position farther forward on the section tested than would have been expected on a true N.A.C.A. 2414 five section. Differences in the position of the transition point could easily account for the slight differences in the profile drag coefficients of the N.A.C.A. 2414 five section found in flight and in the D.V.L. and variable density wind tunnels. The boundary layer surveys showed that transition occurred at a short distance downstream from the point of minimum pressure.

Parachute for Fast Aeroplanes. (American Aviation, Vol. 3, No. 10, 15/10/39, p. 12.) (73/22 U.S.A.)

A new Italian parachute, Salvator D.39, has been designed to resist violent shocks submitted when the jumper leaves a fast military plane. In the device, a canopy has been constructed with an elastic hole in its summit which dilates when the canopy opens, so that the shock is reduced. When speed is stabilised the hole closes gradually until normal braking is realised. The auxiliary extracting parachute is of silk and is provided with a spring which causes it to open in any position. The parachute's total weight is about $17\frac{1}{2}$ lbs.

Calculation of a Steady Turn. (E. V. Ostoslavsky, Aeron. Eng., U.S.S.R., Vol. 13, No. 9, Sept., 1939, pp. 24-43.) (73/23 U.S.S.R.)

By a steady turn is understood one in the horizontal plane at constant angular velocity, constant velocity along the path, constant angle of incidence and constant angle of bank. The mechanics of this manœuvre are quite simple and calculation presents no difficulty, but in the greater majority of cases there is found to be considerable discrepancy between calculated results and actual flying data. The radius of the actual turn is smaller than the calculated value. The present paper attempts to explain the causes of this discrepancy and proposes a more accurate method of calculation.

Numerical results given show the importance of correct choice of initial data, in particular the necessity for correcting the polar curve of the model aeroplane for the effect of re-number, not only in the region of $C_{x\ min}$ as is usually done in aerodynamic calculations, but also in the region of $C_{y\ max}$; the effect of propeller interference must also be taken into account.

Until full and reliable data are obtained by experiment, correction of the polar for change in $C_{y\ max}$ when converting to the re-number corresponding to natural conditions may be made in future by the method described. The slipstream effect may be calculated by the method proposed by V. S. Vedron and the present author. For convenience in calculation a graph is given for determining the requisite coefficient for single-turn and four-engined aircraft.

Aviation on the Ground: Factors Determining the Design of Military Landing Grounds. (Rev. de l'Arm. de l'Air, No. 118, Sept.-Oct., 1939, pp. 483-7.) (73/24 France.)

In order to present minimum vulnerability towards air attack, landing grounds must be designed to have the smallest possible total surface. This requirement leads to the system of tracks, arranged in such a way as to avoid focal points. The system of radiating tracks proposed by Ssegedi is thus eliminated. Natural camouflage (trees, houses) should be left between the runways. The arrangement adopted should also permit:—(1) Normal departing of all the aircraft constituting a tactical unit, either simultaneously or within a short time interval; this can be achieved by take-off in file or simultaneous departure in two or three directions, subsequently assembling in the air; (2) sudden evacuation in case of

attack; (3) rapid removal of any aeroplane which has landed in difficulties, this gives the need for having the tracks in a closed circuit; (4) minimum requirements of men and vehicles for servicing purposes.

The Modern Twin-Fin Tail. (B. S. Shenstone, Aircraft Engineering, Vol. 11, No. 130, Dec., 1939, pp. 442-3.) (73/25 Great Britain.)

Part II. Fins inset from the tips. Curves for induced drag for different fin arrangements plotted from theoretical calculations lead to the following conclusions:—(1) End plate fins are better than inset fins, as far as their effect on tailplane efficiency is concerned. As long as inset fins are outside the half semi-span position the efficiency is considerably higher than that of a single-fin tail, but if the fins are inside the half semi-span position they are hardly better than a single fin. (2) It makes no practical difference to tailplane efficiency whether the fins are all above, below, or symmetrically disposed. (3) The side loads for zero rudder angle, as in the case of end-plate fins, are least for symmetrically arranged inset fins.

Part III. Tail or wings with dihedral.

Conclusions:—(1) Dihedral increases wing efficiency by reducing the induced drag, but to such a small extent for ordinary dihedrals as to be entirely negligible. (2) The effect of splaying out the fins is to decrease the efficiency of the tailplane in comparison with that having fins at 90°.

Sparking Plugs and Octane Rating. (Fuel, Vol. 18, No. 11, Nov., 1939, pp. 318-19.) (73/26 Great Britain.)

F. Fisher and H. Pohl have carried out tests with an I.G. knock testing engine to determine the effect of sparking plug design and material on knocking. The plugs tested had three electrodes of ample section machined from the body proper, thereby eliminating welded or riveted joints, to take full advantage of the high heat conductivity of the metals used. With copper as a body and electrode material, the octane rating of the fuel in use was improved from 54.7, observed with a standard plug to 58.5. This plug gave satisfactory service during the two hours of test. Similar results were obtained with a mica plug equipped with copper electrodes, the improvement in octane number amounting to 2.6 units. With brass electrodes the effect was less, whilst aluminium and lead had no effect.

Detection of Loose Metal in Aircraft Lubricating Systems. (Engineer, Vol. 168, No. 4377, 1/12/39, p. 543.) (73/27 Great Britain.)

One arrangement of the device consists of a grating of metal rods set in the pipe-line, alternate rods being connected with one pole of the electric generator and, via a warning light, with the opposite pole. The warning light is set in the cockpit of the machine and any metal fragments too large to pass through the grating complete the circuit and switch the light on. Fine metallic particles produced in normal engine operation are passed without the warning being given. An alternative arrangement whereby a special plug performs the same function as the grating is also described. The device is the invention of M. Van Os, of the Royal Dutch Air Lines, and the article states that at least twelve cases of engine failure in flight have been averted by warnings given by it.

Modern Aero Engines and Their Performance Characteristics. (E. Vohrer, Luftwissen, Vol. 6, Nos. 9 and 10, Sept. and Oct., 1939, pp. 255-62, 274-7.) (73/28 Germany.)

The present state of aero engine development is reviewed and at the same time the limits within which the performance figures vary are indicated. The following results are arrived at:—

For cylinders of over 1.5 litres the power per litre reaches 40 h.p.; for cylinders below 1 litre the figure is 58 h.p. The most powerful engines do not have the

highest power per litre since they are limited by low speed of revolution. High output per unit volume can only be attained by high speed of revolution in conjunction with decrease in the cylinder dimensions. The peak value for the piston velocity lies at 16 m./sec.; most frequently the value is 12-14 m./sec. with stroke-bore ratios between 1.09 and 1.13. The maximum mean effective pressure is 14.3 kg./cm.^{2}, values of 12-13 kg./cm.^{2} being common for modern supercharged engines; on going over from 87 octane fuel to 100 octane fuel these figures are increased by 30 per cent. For the power loading of the pistons values between 0.35 and 0.68 h.p./cm.^{2} are obtained. The increase in power with altitude (supercharge pressure and engine speed constant) varies between 3 and 4.75 per kilometre altitude. With one exception (Bristol " Pegasus " XXIII) there is no engine in existence weighing less than 0.5 h.p./kg., if the weight of the cooler is taken into account in the case of liquid-cooled engines. The weights per unit of swept volume vary between 14 and 28 kg./l. With modern liquid-cooled engines it has already been possible to reduce the cross-section of the engine group to 1,750 h.p./m.^{2}.

Vapour Phase Cooling for Internal Combustion Engines. (J. H. Wallace and R. A. Newton, Oil Gas J., Vol. 38, No. 17, 7/9/39, p. 58.) (73/29 U.S.A.)

A new method of engine cooling termed vapour phase cooling, involves the use of a liquid at or near its boiling point. Tests on a typical cylinder showed that irrespective of the average temperature of the jacket water, the water in the upper jackets and heads is at boiling point while 10-15 times the normal water flow would be required to keep the metal temperatures to within 20°F. of that of the water. High jacket temperatures reduce liner distortion, increase mechanical efficiency by up to 10 per cent., but have little effect on thermal or volumetric efficiency while reducing moisture condensation in the cylinder. The ideal jacket water temperature is obviously near boiling point, but this cannot be maintained in normal systems. The vapour phase cooling system which has now been developed consists essentially of a flash chamber in which the jacket water is circulated and from which steam-free water is returned by pump to the jacket. The circulation rate is approximately 0.4 gall./min. per b.h.p. and is sufficient to maintain a difference of not more than 20°F. The advantages of the system are enumerated. Results of practical tests indicate an improvement in the condition of the engine and of the lubricating oil after installation of these systems.

Production of Fuel Oil from Sewage Sludge (from the Japanese). (S. Sibata, Fuel, Vol. 18, No. 11, November, 1939, p. 318.) (73/30 Japan.)

S. Sibata, in the Journal of the Fuel Society of Japan for April, 1939, describes experiments on the production of fuel oil from sewage sludges. He claims to have obtained fuel oil by retorting the digested residues of sewage solids, the amount being equivalent to 9 to 12 per cent. of the retorted material. Similar treatment of undigested raw activated sludge resulted in an oil yield of about 17.5 per cent. of the material treated. The oil obtained was rich in oxygen and nitrogen, its unsaturated and aromatic hydrocarbon contents were high, and its gasoline fraction was greater than that of ordinary natural petroleum. The quality of the oil could be considerably improved by hydrogenation, whereby the nitrogen was removed as ammonia, the oxygen as water and the unsaturated hydrocarbons converted into saturated compounds.

It is pointed out that, although retorting of the raw activated sludge yields about 17 per cent. of fuel oil as compared with a smaller amount from digested sludge, digestion is essential because of the offensive odour and because during digestion, which is carried out by allowing the sludges to ferment in a tank for 20 to 30 days, methane is evolved which is used for retort heating. The retort is of the rotary type, its inside temperature being 450 deg. Cent.

A New Anti-Knock Agent for Motor Fuel. Substitute for Tetra-Ethyl Lead. (E. Belani, Chemiker Zeitung, No. 37, 10/5/39.) (73/31 Germany.)

Furfurol ($C_5H_4O_2$) is obtained from a few petroleums and from many waste products, *e.g.*, grain distilleries products, wood carbonisation liquors, etc. The latest method of production is from sawdust or oat husks, which yield 11 per cent. furfurol.

It is itself non-explosive but extends the explosion limits of compressed gases in both directions. It imparts increased knock stability to motor fuels and by promoting complete combustion gives considerable economy in fuel consumption. Carbon and tar deposits on sparking plugs are reduced so that ignition is more reliable and the running of the engine more smooth, thereby reducing stresses in the moving parts. Furfurol also has a certain lubricating effect and its high flame point reduces the danger of carburettor fires. Many large American companies, such as the Texas Gulf Company, are already using large quantities of furfurol as an anti-knock, thereby reaching knock-ratings of 99. Addition of furfurol does not reduce lead sensitivity. As a substitute for tetra-ethyl lead the Standard Oil Co. is using a mixture of metal carbonyls such as $Fe(Co)_4$, $Fe(CO)_5$, $Fe(CO)_6$, $Co(CO)_3$, $Co(CO)_4$, $Ni(CO)_4$, $Mo(CO)_6$, with furfurol and amines.

Furfurol is also added to lubricating oils in small quantities to improve their properties.

Hydrogen as a Motor Fuel. (M. Oehmichen, Autom. Tech. Zeit., Vol. 42, No. 21, 10/11/39, pp. 573-6.) (73/32 Germany.)

Water with addition of NaOH, is electrolised under pressure by means of direct current, the pressure being up to several hundred atmospheres. The gas thus obtained is considerably cleaner and contains less moisture than that obtained by other methods.

Bomb experiments on the effect of preliminary compression on combustion of hydrogen-air mixtures appear to show that under engine conditions the velocity of combustion will be about 100 m./sec. Assuming that the flame front runs at right angles to the cylinder axis from the centrally situated ignition point, then for a cylinder of 100 mm. diameter the mixture will be burnt through in about 1/2,000 sec., which corresponds to 3° of crank angle if the engine speed is 1,000 rev./min. At a calorific value of 711 kcal./m.^{3} (corresponding to an air excess number $\lambda = 1.0$), a rough allowance for heat losses gives a pressure rise of about 50 atm., *i.e.*, about 16.7 atm. per degree crank angle. This compares favourably with many Diesel engines.

The conclusion to be drawn from bomb experiments is that hydrogen appears to be a difficult fuel to deal with. The large extent of the ignition range indicates that careful adjustment of the mixture will be necessary, as too great dilution will give too slow burning accompanied by high heat losses. Researches on the use of hydrogen as an engine fuel are reviewed with special reference to the Erren hydrogen engine.

Measurement of Anti-Knock Values in Otto Engines. (R. Schutz, Deutsche Kraftfahrtforsch., No. 31, 1939, 22 pp. Chem. Absts., Vol. 33, 1939, p. 8971.) (73/33 Germany.)

A critical discussion is given of the factors affecting determination of engine knock by the bouncing pin method, based on experiments with commercially available indicators and one designed by the author. In the latter an electro-magnetic induction coil mounted on the bouncing pin serves for recording the velocity of the pin. Generally, the bouncing pin indicator readings are adversely affected by the natural oscillation of the membrane, burned contact points and the natural oscillation of the contact springs. The values measured depend not only on the rate of pressure rise, but also usually on the final combustion pres-

sure and rate of expansion. None of these three factors being directly correlated to the knocking process it is unlikely that knock intensity can be correctly determined with the bouncing pin. Regardless of whether a " knocking oscillation " is revealed in the pressure diagram or not, knock frequencies can be determined from the vibrations of the engine by the use of amplifier circuits; however, only average values of knock intensity can be obtained in this way. Determination of the knock centre in the combustion chamber by means of the quartz window device or of the flame velocity by the ionisation method gives valuable information on the combustion process. Measurement of the spark advance angle at incipient knock serves the same purpose, but only average values should be considered.

Chemistry of Aircraft Lubricating Oils. (C. M. Larson, Oil Gas J., Vol. 37, No. 39, 1939, pp. 46, 48, 67-8. Chem. Absts., Vol. 33, 1939, p. 8974.) (73/34 U.S.A.)

The Saybolt universal viscosity of aircraft lubricating oils at the inlet should be less than 2,800 sec. for normal take-off, 6,000 sec. for emergency take-off and for operation 500-110 sec. Viscosity characteristics of the oils used by transport airlines, the navy and the army are given. Addition agents such as paratone and acrylic ester are being used in some cases to improve viscosity index. The navy work factor (U.S. Bureau of Eng. Bull. N. and Eng., 31, 1937) and the U.S. army oxidation test (Mo 29 L.A, March 1, F-5) are used to determine stability to oxidation and sludge formation. Carbon residue is used to determine degree of refining. Iron salts picked up by the oil accelerate oxidation. Phosphates are being tried as anti-oxidants. Oil sludge analysis is a poor index for ring sticking, deposits, etc. Full-scale 50-hour endurance tests, using a scoring method (briefly described), are recommended by one engine manufacturer. Neutralisation number is not a reliable index of corrosiveness because values between laboratories vary by 300 per cent. Of the oiliness agents, including ketones, esters and phosphates, the ketones are effective, phosphates tend to combine with lead from the fuel and deposit salts in ring grooves and on exhaust valve stems, while with unleaded fuels deposits of H_3PO_4 are found. Oiliness agents can be tested only in flight.

The Friction Between Metals in the Presence of Lubricants. (G. M. Panchenkov and K. V. Konstantinova, J. Techn. Phys., U.S.S.R., Vol. 9, 1939, pp. 537-44. Chem Absts., Vol. 33, 1939, p. 8975.) (73/35 U.S.S.R.)

The coefficient of static friction μ between polished metals lubricated by mineral oils is lowered by cyclohexanol, cetyl alcohol and oleic, palmitic and stearic acids. Increasing the quantity added up to 2-3 per cent. decreases the static friction, while additions of α-naphthylamine or octyl alcohol give a minimum value of μ at 1-1.5 per cent. At a constant concentration of the addition agent is higher the smaller the viscosity of the mineral oil. The lowering of μ produced by these additions varies according to the nature of the metal (steel, iron, brass, etc.). The effect of the additions on μ is different from their influence on the interfacial tension between oil and water.

Peroxides and Detonation in Internal Combustion Engines. (A. S. Sokolik, Acta Physiocochim, U.S.S.R., Vol. 9, 1938, pp. 593-620. Chem. Absts., Vol. 33, 1939, p. 9586.) (73/36 U.S.S.R.)

The nuclear idea of the peroxide theory is no longer tenable. Peroxides which are formed during compression, are primary oxidation products and furnish active centres for the subsequent oxidation of the hydrocarbon by a chain reaction mechanism. Detonation is caused by sudden variation in the kinetic properties during the very short delay period and subsequent explosion wave. For detonation to occur, a certain concentration of peroxides must be reached immediately before ignition of the last portion of the charge. The maximum concentration

of peroxides very nearly coincides with the appearance of the cold flame; the concentration of aldehydes increases for some time thereafter, coinciding with the dissociation of peroxides. Experimental results show that detonation decreases both through slowing down the original oxidation reaction and also through its premature development and consequent degradation of the detonating properties of the mixture as a result of premature dissociation of peroxides. The oxidation of di-isopropyl ether is discussed as an example of the latter type, and the effects of preheating and of engine speed are mentioned. Cracked gasolines show less anti-knock properties when preheated than do straight run gasolines of the same octane number.

Nomographic Study of the Viscosity of Lubricating Oils as a Function of Temperature. (J. Groff, Ann. soc. belge etude petrole, Vol. 3, No. 12, 1939, pp. 27-31. Chem. Absts., Vol. 33, 1939, p. 9614.) (73/37 Belgium.)

It is shown how to construct nomograms representing:—(1) The viscosity temperature characteristics of an oil in the various conventional viscosity scales to enable an easy conversion; (2) the Dean and Davis viscosity indexes of oils of different S.A.E. viscosities; (3) the Saybolt viscosity ratio; or (4) the circulation coefficient, *i.e.*, the priming ability of the oils in a pump. The latter nomogram also shows the optimum viscosity index of mixtures of two or three oils, provided that no complex molecular association takes place. Viscosity changes due to crankcase dilution, etc., can likewise be evaluated from this nomogram.

Gasoline Engine Combustion. (H. Rabezzana, S. Kalmar and A. Candelise, Autom. Ind., Vol. 81, No. 10, 15/11/39, pp. 534-42.) (73/38 U.S.A.)

Engine combustion is analysed by treating separately the two simultaneous phenomena of burning and expansion of the reaction zone. Small elements of volume burn at constant volume, then expand into both the previously burned and the still unburned portion of the mixture until pressure equilibrium is reached. As the reaction progresses each element burns under different conditions of pressure, temperature and chamber volume. The time taken for a given linear flame displacement in space is determined by the reaction velocity—the linear rate at which the flame travels with respect to the unburned gas. The relationship between flame velocity and reaction velocity is deduced and a method given for predetermining the pressure-time characteristics of a combustion chamber design. Analysis of pressure and flame records obtained in various types of combustion chambers and under various conditions shows the effect of such factors as mixture ratio, induction and compression turbulence, spark advance, chamber contour, etc., etc., on reaction velocity. It is shown that the duration of the entire combustion cycle, depending mainly on the reaction velocity, controls the peak pressure and also detonation. Hence, for given fuel-air mixtures, there is a definite relationship between the maximum pressure obtainable without detonation and the time elapsed from ignition. The initial stage of combustion is the most sensitive towards the various factors which affect reaction velocity.

An Audio-Frequency Spectrometer. (R. K. Hellman, Instruments, Oct., 1939, pp. 277-9. Met. Vick. Tech. News Bull., No. 684, 10/11/39, p. 6.) (73/39 Great Britain.)

An electric wave analyser, permitting instantaneous measurement of the amplitudes of any frequency components present in a complex sound or electric wave, is described. Since all the components to be analysed are made visible simultaneously, the spectrum of the wave to be analysed is shown as in optical technique. Although the frequency range of the device is immaterial, its design makes it particularly suitable for audio and supersonic frequencies.

The Electron Raster Microscope. (R. Kompfner, Electrotecnica, Nov., 1939, pp. 635-7. Met. Vick. Tech. News Bull., No. 685, 17/11/39, p. 9.) (73/40 Great Britain.)

The limitations of the conventional electron microscope are due to lens aberrations and geometrical considerations. Further, it is essential to insert the object to be examined into the vacuum tube by means of an airlock. This necessitates keeping vacuum pumps and H.T. equipment going and critical adjustments of th focal length of the coils. It is claimed that the electron Raster microscope overcomes these difficulties. The principle of the microscope is as follows:—A thin electron beam is made to scan the object in a " Raster " as in television. The electrons pass through the object and holder and impinge on a collecting electrode and are converted into current impulses. These impulses are amplified and reproduced on the fluorescent screen of a cathode ray tube whose electron beam is made to move in synchronism with the electron pencil in the microscope.

An Instrument for Estimating Tautness of Doped Fabrics on Aircraft. (G. M. Kline and H. F. Schiefer, N.A.C.A. Tech. Note No. 729, Sept., 1939.) (73/41 U.S.A.)

The linear deflections of doped fabrics under a given load are used as criteria for comparing the tautness of various panels. The usual type of tautness meter employs weights for loading, and can be used only on approximately horizontal surfaces. This prevents its use on many parts of aircraft. A spring-loaded tautness meter has therefore been developed which can be used in both horizontal and vertical positions. Results of tests made on the fabric coverings of various aeroplanes are reported and discussed. It is concluded that the actual deflection of the fabric under the arbitrary 1 lb. load, irrespective of the distance between ribs, is a more reliable criterion of the tautness on the assumption of a linear relation between deflection and spacing. A desirable limit to the maximum deflection under a 1 lb. load as measured by the method described is 0.100 inch.

Dynamic Balancing. (J. Craig Jones, Aircraft Production, Vol. 1, No. 14, December, 1939, pp. 484-6.) (73/42 Great Britain.)

Having discussed the theory of balancing and the most common methods for determining out-of-balance, the Olsen " E.O." type balancing machine is described. This works on an entirely new principle and is capable of handling exceptionally small parts. The machine is made in several sizes, the smallest size being capable of handling parts weighing a maximum of 5 lb. and a minimum of 5 ozs. This type of balancing machine is capable of denoting the amount and position of out-of-balance weight by either mechanical or electrical means.

The Buckling Strength of Circular Symmetrically Stepped Plates. (F. A. Willers, Z.A.M.M., Vol. 19, No. 4, August, 1939, pp. 206-210.) (73/43 Germany.)

Starting with an expression for the potential energy of the buckled plate, the author develops the differential equations for buckling under radial compression, the edge of the plate being either fixed or allowed to rotate.

Under these conditions, a vertical plate may buckle as a whole either to the left or right, or the buckling may occur along nodal lines, partly to the left and partly to the right. The smallest buckling load corresponds to the first case, as would be expected.

The author next considers the case of a singly stepped plate, the increase in plate thickness being 100 per cent. at the step. The reinforcement is assumed to start at the centre of the plate and the buckling loads corresponding to a gradual increase in the diameter of the step are calculated. Similar calculations are carried out when the increase in thickness starts at the edge instead of the

middle. In either case both clamped and a free edge (bending) is considered.

It appears that an increase in " stepped " thickness spreading from the outer edge towards the centre produces always a smaller buckling load than if the same weight of material were spread uniformly over the disc.

If the reinforcing step starts, however, at the centre the buckling load for the supported plate is appreciably greater than if the same material is spread uniformly over the disc.

Small Oscillations of a Rope Suspended with Considerable Sag. (H. Seitter, Z.A.M.M., Vol. 19, No. 4, August, 1939, pp. 211-215.) (73/44 Germany.)

The rope of a given length $2\,S_0$ is assumed to be perfectly flexible, inextensible and without weight. It is suspended without friction at two supports in the same horizontal plane a distance $2\,x_0$ apart so that it assumes a symmetrical shape under the action of a vertical load q per unit length.

The author investigates the frequency of small symmetrical oscillations about the equilibrium of a system of this nature. With sufficient sag, the frequency is determined completely by the geometry of the system. Thus it suffices to know either S_0 and q or S_0 and X_0. In a particular case, where $\begin{cases} 2\,x_0 = 200 \text{ cm.} \\ 2\,s_0 = 209.4 \text{ cm.} \end{cases}$ the fundamental frequency is 2.81 vibrations/sec.

Resonance Vibrations of a System Subjected to Vectorial Forcing Impulses. (G. Heinrich, Z.A.M.M., Vol. 19, No. 4, August, 1939, pp. 216-223.) (73/45 Germany.)

In practice, cases of vibration often arise in which the forcing impulses alter their direction according to a definite law. As an example we may take the transverse vibrations of a flywheel interposed between two crank throws. Each working stroke produces an impulse of varying amount, but constant direction with reference to a stationary observer. If the system of co-ordinates, however, is attached to the flywheel, the impulse vector will undergo a regular rotation, provided the flywheel is turning uniformly.

The author considers the general case of a body with rotational symmetry capable of vibrating with the same frequency about any axis passing through a certain point O on the axis of symmetry and perpendicular to the latter. The body itself is assumed to be rigid, the vibrations being made possible by the introduction of suitable spring forces. The forcing of these vibrations is due to rotary impulse, the vectors of which are all contained in a plane passing through O and perpendicular to the axis of symmetry. The conditions of resonance are examined for the two cases of discreet and continuous forcing impulses respectively.

On the Frequency of Flexural Vibrations of a Rotating Propeller Blade. (K. Sezawa and I. Utida, Aer. Res. Inst., Tokyo Rept., No. 181, August, 1939.) (73/46 Japan.)

The methods of calculation usually applied in determining the frequency of vibration of a blade in rotation are not satisfactory from the theoretical point of view. An exact method for calculating frequency is proposed, but since the calculation is extremely complex the problem is restricted to the case in which the blade has a uniform cross-section. Calculated results show that for the frequency of vibration of any higher order than the first harmonic the coefficient denoting the effect of speed of rotation on the frequency of vibration must be increased enormously over that previously employed. On the other hand, the frequency of the fundamental vibration does not differ much, whatever method of calculation is employed.

Experimental Study of Torsional Column Failure. (A. S. Niles, N.A.C.A. Tech. Note No. 733, Oct., 1939.) (73/47 U.S.A.)

Compression tests have been carried out on thirty-three open channels (dimensions $2 \times 2 \times 0.1$ in.) of 24 ST. aluminium alloy in order to test the validity of the theoretical formulæ for torsional failure developed by E. E. Lundquist of the N.A.C.A. The results obtained for the critical loads and the positions of the twist axis were sufficiently near to those given by the formulæ to establish the substantial validity of the latter. The differences between the observed and computed results were small enough to be accounted for by small and mostly unavoidable differences between the test conditions and those assumed in deducing the formulæ. Some data were obtained from the shorter specimens regarding the growth of buckles which resulted in local buckling failure.

The formulæ for torsional failure deduced by the Lundquist procedure may be employed with confidence by designers provided that formulæ based on suitable boundary conditions are selected. The importance of torsional failure of open sections is shown by the fact that the critical loads of the specimens which failed torsionally were far below those indicated by the usual column formulæ.

Investigation of the Impact Bending Strength of Synthetic Resins. (W. Kuntze and R. Nitsche, Kunststoffe, Vol. 29, No. 2, 1939, pp. 33-41.) (73/48 Germany.)

These investigations were carried out for the V.D.I. on mouldable phenol resins (with and without fillers or reinforcing materials) and on mouldable urea resins, and are to be used as a basis for specifications for testing the impact bending strength of synthetic resins. The pendulum impact test machine used gave a maximum loading of 10 mkg., and other series of experiments were also carried out at maximum loadings of 1.5 and 0.4 mkg. The impact weights were from 0.8 to 8 kg., the impact velocities from 0.5 to 9 m./sec. The materials were tested in the usual form of a prismatic bar ($120 \times 15 \times 10$ mm.^{3}). It was found that :—The impact work increases with impact velocity but is almost independent of impact mass. With increasing impact velocity the relative values for the velocity dependency and the amount of scattering decrease, but the absolute values increase. Fibrous and stratified reinforcing materials lead to greater values for the impact work. The fractures are characteristic for each type of material, independent of the velocity or impact weight which has produced fracture. On the other hand, pictures of the structure of a synthetic resin give practically no basis for judging its strength properties.

Effect of Internal Stresses on the Resistance of Materials Towards Splintering and Wear. (N. Sawin, Werkstattstechn, Vol. 33, No. 12, 1939, pp. 301-4.) (73/49 Germany.)

Any kind of chipping or shaving treatment is accompanied by thermal effects and permanent deformations, thereby causing inherent stresses in the machined part which are greatest at the treated surface. Surface smoothing by rolling also causes stresses in a material, which reduce its resistance towards cutting, grinding and wear. This was proved by an abrasion test on the Skoda-Sawin machine using a Widia abrasion disc. Roughening at low cutting velocity in the unhardened state, as well as ordinary grinding after annealing, considerably reduce the resistance towards abrasion with the Widia disc, although there is very little effect on hardness. Twenty per cent. reductions in the relative work required for abrasion were quite common in the case of steels which had previously been subjected to a shaving treatment. These working stresses can be removed to a considerable extent by annealing and very careful polishing, which again gives a corresponding increase in the abrasion resistance and in the work required for cutting and grinding.

The Anodic Protection of Magnesium. (J. Frasch, Métaux et Corrosion, Vol. 14, 1939, pp. 83-96. Chem. Absts., Vol. 33, No. 20, 20/10/39, p. 8121.) (73/50 U.S.A.)

The formation of an oxide film by anodic oxidation does not protect magnesium from corrosion, but the film can serve as a base for paint. Silicate, aluminate and phosphate coatings prevent corrosion to some extent, but they are too thin and porous. Better protection is obtained by electrolytic production of chromium or manganese oxides on the surface of the magnesium, using alternating current, followed by reduction of the oxides with hydrogen. Solutions of manganese carbonate and of potassium permanganate in chromic acid were used to test the anodic protection of magnesium. An oxide film of 4-5 μ offers sufficient protection. To obtain a uniform deposit the surface of the metal must be thoroughly degreased and descaled before the anodic treatment. Best results were obtained by letting the hydrogen over-voltage reach the maximum before closing the circuit, which takes 1-4 min. The oxides formed on magnesium by the anodic treatment are dehydrated by immersion for 5 min. in paraffin at 190°. Salt spray test of anodically treated magnesium alloys shows a corrosion resistance lasting two months for sheets of 1.8 per cent. Mn alloy, one month for sheets containing 6 per cent. Al, 1 per cent. Zn and 0.4 Mn, four weeks for forged alloy containing 3 per cent. Al, 1 per cent. Zn, and 0.4 per cent Mn, and three weeks for forged alloy containing 8.5 per cent. Al, 0.5 per cent. Zn and 0.4 per cent. Mn.

The Properties of Light Metal Welds. (P. Brenner, Metal Ind., 10/11/39, pp. 405-8. Met. Vick. Tech. News Bull., No. 685, 17/11/39, p. 4.) (73/51 Great Britain.)

A survey is made of the corrosion resistance and other properties of certain light metals after gas butt welding. The materials used in the tests were, pure aluminium, aluminium-manganese, aluminium-magnesium-manganese, aluminium-magnesium-silicon and aluminium-copper-magnesium alloys, and in each case a butt weld on 1.5 mm. sheet was made. The method adopted for corrosion resistance tests was the stirring test of Din 4853, using a 3 per cent. sodium chloride solution containing 0.1 per cent. hydrogen peroxide. At various intervals of time several test pieces were withdrawn from the solutions for determination of the decrease in tensile strength and for detailed metallographic examination. The results of the tests show that greatest resistance to corrosion is exhibited by pure aluminium, aluminium-manganese and aluminium-magnesium-manganese alloys, both in the welded and unwelded condition.

Isopachic Stress Patterns. (M. M. Frocht, J. Appl. Physics, Vol. 10, 1939, pp. 248-57.) (73/52 U.S.A.)

In optical stress investigations the term isopachics is used to denote the lines of constant alteration in thickness, which, assuming Hook's law to hold, also represent the lines of constant total stress (as determined graphically from the isoclines and isochromatics). The author determines the isopachics by the interference lines method. The present paper describes further experimental development of the method and gives an accurate description of the experimental arrangement. A coloured light is used (mercury vapour lamp) which, after passing through a condensing lens, is reflected at 45° from a glass plate and falls on a special interferometer prism; the light reflected from the latter reaches the air space between the prism and the model (breadth of the air space proportional to the change in thickness) and is finally reflected again at the polished surface of the model. The author used steel for the test model and obtains satisfactory results in the case of a diametrically-loaded circular ring disc.

Recovery Recrystallisation and Creep Behaviour of a Few, Cold-Worked, Austenitic Materials. (H. Cornelius, Metallwirtsch, Vol. 18, 1939, pp. 399-403, 419-21.) (73/53 Japan.)

Since the recovery temperatures of austenitic materials lie very high, during the course of studies of heat-stable materials for parts of internal combustion engines subjected to stress at high temperature (*e.g.*, valves), attention has been paid at the D.V.L. to the possibility of improving the creep behaviour of austenitic materials by cold working. Information regarding the possible alteration in strength properties during fatigue stressing was obtained by carrying out tension tests at room temperature before and after the fatigue test. The test materials were :—

1. A Cr-Ni steel with additions of W, Ta and Nb.
2. A carbon-containing Cr Ni Fe Ti alloy.
3. A Ni Co Cr Fe W alloy.

RESULTS.—Cold stretching gives an improvement in creep properties up to a definite temperature of fatigue stressing. However, above this temperature the creep behaviour of the cold-stretched material is worse than that of the soft-annealed material. The extent to which the creep behaviour of austenitic materials can be influenced by cold working, as well as temperature limit up to which the treatment has a beneficial effect, has to be determined experimentally for each individual case. The lowering of the recovery temperature, due to tension stress, was not shown clearly in any of the present experiments. As regards static strength properties, particularly from the point of view of deformability, the cold-worked materials are not more unfavourably affected by fatigue stressing at high temperature than the unworked material.

Contact Corrosion of Pure Aluminium with Various Metals, in Particular Stainless Steel. (W. Geller, Korrosion u. Metallsch., Vol. 15, No. 9, 1939, pp. 298-304.) (73/54 Germany.)

Results of experiments carried out with sheet metal samples to determine the contact corrosion of pure aluminium in conjunction with stainless steel, copper and iron, show that steels of low nickel content or free from nickel behave in practically the same way as the high nickel content 18/8 Cr-Ni steel, the contact effect is many times smaller by comparison with copper or iron. Measurements of potential made after various corrosion periods showed that the aluminium-stainless steel elements can be very strongly polarised, but in absence of current high potential differences can occur. Therefore insulation of the metals is always to be recommended, particularly when subjected to the continuous action of liquid. Contact corrosion and polarisation depend strongly on the prevailing conditions. Corrosion phenomena due to the effects of cracks are considerably increased by contact currents.

On the Combined Effect of Cold Working and Hardening at Room Temperature on Aluminium-Copper-Magnesium Alloys. (H. Kostron, Zeit fur Metallkunde, Vol. 31, No. 11, November, 1939, pp. 329, pp. 329-334.) (73/55 Germany.)

It is known that cold working carried out immediately after quenching accelerates the subsequent hardening of aluminium-copper-magnesium alloys at room temperature, but reduces the amount of hardening. An attempt is made to explain this as due to the fact that cold working favours the hardening process and therefore allows it to take place more completely, but at the same time it lowers the efficiency of the hardening process, because the latter takes place predominantly in the worked material, at the parts which have already been hardened by cold working. Apart from this change in the efficiency of the method, cold working also appears to cause an alteration in the mechanism of hardening; determinations of the grid constants show that demixing of the supersaturated

solid solution occurs. These conclusions are strengthened by observations of the subsequent hardening which follows repeated working of a material which after quenching, has been worked to a different degree and then hardened; in this case it is found that hardening of the material takes place more completely the greater the preliminary working; the reduction in the degree of hardening can thus only be explained by the deterioration in efficiency. Experimental results obtained by K. L. Dreyer can also be explained by a change in efficiency of this type or by the assumption that after cold working more stable hardening conditions are realised than after normal hardening at room temperature.

Torsion and Flexure. (C. Gurney, Aircraft Engineering, Vol. 11, No. 130, Dec., 1939, pp. 437-440.) (73/56 Great Britain.)

Solutions for flexure of a thin blade, and torsion of a thin-walled tube have been obtained without the use of stress functions—compatibility being introduced as a geometric condition. The shear deflection of a thin blade is shown to be the same as the deflection obtained by assuming a uniform shear distribution across the depth of the section—a conclusion different from that drawn in a well known text book. If axial warping is prevented at the root section it can be shown that the deflection will be less than that given in this paper. The Bredt formula and the first terms of Duncan's series approximation for torsion of thin walled tubes are obtained by a method similar to that used for flexure. Solutions for flexure of plate web girders and thin-walled tubes are not given here, but they can be obtained by a process identical with that used for flexure of the blade.

Thermoflux Method for Measuring Thickness of a Plate. (Fuel, Vol. 18, No. 11, Nov., 1939, p. 318.) (73/57 Great Britain.)

In the maintenance of boilers and other pressure vessels it is frequently desirable to measure the thickness of the plates in order to determine the extent to which corrosion has taken place. Direct measurement is often impossible, and the drilling of test holes is obviously undesirable. The Thermoflux method of testing is based on the variation of the thermal conductivity of steel plates with the thickness. Heat is generated in the plate by applying an alternating current magnetic yoke to the outer surface and a thermocouple is applied to the plate between the legs of the yoke. The rise in temperature indicated by the couple after a definite time interval is a function of the thickness and magnetic properties of the plate. With boiler plates of normal composition the variation in magnetic properties is slight, so that with the aid of calibration charts the thickness of the plate can readily be estimated with an accuracy of ± 5 per cent. Scale up to 0.002 in. in thickness beneath the poles of the magnet is not important, but the thermocouple must be in contact with clean metal.

Corrections are necessary if the instrument is used in the vicinity of abrupt changes of section, but still water in contact with the inner surface of the plate does not affect the consistency of the readings, although an appropriate calibration of the instrument is required.

Metal Photographic Film. (Fuel, Vol. 18, No. 11, Nov., 1939, p. 318.) (73/58 Great Britain.)

Several announcements have recently been published concerning the use of metallic materials as supports for photographic emulsions in place of paper or celluloid. Mining and metallurgy (September, 1939) states that in the U.S.A. the backing material is to be an alloy containing 92 per cent. of aluminium with a standard thickness, for normal use, of 0.004 in. The metal will be available in rolls up to 36 in. wide and in sheets up to 8 by 10 ft. The weight will be the same as ordinary acetate or nitrate film or double weight paper and the cost will be lower. Several advantages are claimed for the metal-backed emulsions,

Processing can be more rapid, since solutions will not penetrate the base and washing is therefore facilitated, whilst drying can be accelerated by the use of temperatures up to 400 deg. Fahr. Since the metal film will neither shrink nor stretch during processing, it should be of particular value when it is necessary to take precise measurements from a photographic record as in aerial mapping, spectography, and in the recording of transient phenomena.

In the projection of metal base cinematograph films it is necessary to use reflected light from both picture and sound track, but this is said to present little difficulty, as the film is non-inflammable and the intensity of the source of light can safely be increased to the necessary value. Economy in film may be obtained by using both sides of the film, and by a suitable arrangement of the sequences of a multi-reel film it should be possible to avoid re-winding.

Metal film is also suited to very high speed photography, as the film can be run at speeds which would result in the tearing of a cellulose base.

Sigal, the High Grade German Protective Paint Pigmented with Aluminium-Silicon. (F. Kipping, Metallges. Periodic Rev., Vol. 14, 1939, pp. 27-31. Chem Absts., Vol. 33, 1939, p. 9012.) (73/59 Germany.)

"Sigal" is the name of a rust-inhibiting pigment based on the corrosion-resistant properties of Al-Si alloy. It consists essentially of the eutectic alloy 87 per cent. Al, 13 per cent. Si with the addition of elementary Si; the whole is ground to a fine powder in a ball mill with air separation so that no residue is left on a sieve of 16,000 mesh/sq. cm. The film is very elastic, the elasticity increasing with increasing substitution of resinous material for linseed oil; it is superior to a film of red lead + white lead + linseed oil. Sigal priming coats are made up without addition of oil, while finishing coats contain up to 5.8 per cent. linseed only. Favourable results of almost eight years' observation on outdoor structures are described.

LIST OF SELECTED TRANSLATIONS.

NOTE.—Applications for the loan of copies of translations mentioned below should be addressed to the Under-Secretary of State (R.T.P.), Air Ministry, Dept. Z.A., London, W.C.2, and will be supplied as far as availability of stocks permit. Suggestions concerning new translations will be considered in relation to general interest and facilities available.

Lists of selected translations have appeared in this publication since September, 1938.

TRANSLATION NUMBER AND AUTHOR.	TITLE AND JOURNAL.
	THEORY OF WARFARE.
981 Malvani, M.	*Machine Gun Defence Against Low-Flying Aircraft.* (Rassegna di Culture Militare-Rivista di Fanteria, Vol. 1, No. 6, June, 1938, pp. 293-299, and No. 7-8, July-August, 1938, pp. 341-355.)
988 Bachofner, Capt. ...	*Bomb Ballistics.* (Flugwehr-und Technik, Vol. 1, No. 5, May, 1939, pp. 136-138; No. 6, June, 1939, pp. 148-151; No. 7, July, 1939, pp. 178-9.)
	MATERIALS AND ELASTICITY.
954 Köller, H.	*Effect of Alterations in Stiffness on the Force Distribution in Statistically Indeterminate Frameworks.* (Jahrbuch der deutschen Luftfahrtforschung, 1938, Vol. 1, pp. 444-51.)

TRANSLATION NUMBER AND AUTHOR.		TITLE AND JOURNAL.
984	Dehlinger, U. ...	*Is There a True Creep Limit?* (Z. Metallk., Vol. 31, No. 6, June, 1939, pp. 187-91.)
		AERODYNAMICS AND HYDRODYNAMICS.
959	Ehret, L.	*The Propagation of Plane Waves of Large Amplitude in Gases.* (Jahrbuch der deutschen Luftfahrtforschung, 1938, Vol. 2, pp. 53-61.)
979	Cremona, C.	*Investigations and Tests in the Towing Basin at Guidonia.* (Hauptversammlung der Lilienthal-Gesellschaft für Luftfahrtforschung, Berlin, October 12-15, 1938.) (N.A.C.A. Technical Memorandum 892.)
		AIRCRAFT AND ACCESSORIES.
978	Schmidt, R.	*The Effect of the Masses of the Controls on the Longitudinal Stability with Free Elevator.* (L.F.F., Vol. 16, No. 1, 10/1/39, pp. 31-7.) (N.A.C.A. Technical Memorandum 900.)
982	Eujen, E.	*Measurement in Flight of the Effect of the Propeller Slipstream and Landing-Flap Deflection on the Downwash and the Dynamic Pressure at the Tail.* (L.F.F., Vol. 16, No. 1, 10/1/39, pp. 38/46.)
		MISCELLANEOUS.
948	Clamann, H. G. ...	*Curves Representing the Adaptability of the Eye to Darkness in the Case of Deficiency of Oxygen.* (Jahrbuch der deutschen Luftfahrtforschung, 1938, Vol. 3, pp. 89-90.)
949	Schardin, H.	*Toepler's Striation Method. Principles for its Application and Quantitative Evaluation.* (Forschungsheft, No. 367, July-Aug., 1934.)

REVIEWS.

THE WORLD OF WINGS AND THINGS.

Sir Alliott Verdon-Roe, O.B.E., F.R.Ae.S., M.I.Ae.E. Hurst and Blackett. 1939. 7/6 net.

He'll always be "A.V." despite the Alliott, and as A.V. he will always be welcome, because the air does not easily forget its old friends. But like all old friends he has his faults and failings as well as his good points and both sides of this great pioneer come out in his book of recollections. As Oliver Stuart says in his preface, "Execution, probation, canonisation; these are the three stages in the progress of the pioneer." But saints are not of this world.

Now A. V. Roe has written a book full of interest and full of inspiration. At the early age of 14 he sailed for British Columbia, ostensibly to learn surveying, but actually to plant trees at the magnificent wage of 16/- a day, and catching fish to sell to ships. Even in those early days his organising ability showed

itself, for he soon found he could make better profits by getting Indians to do the fishing and selling himself to the ships.

A year later he was back in England apprenticed to a railway company, and winning large financial prizes in cycling competitions. After his apprenticeship he studied marine engineering and became an engineer with the British and African Royal Mail Company. Here, watching albatrosses in flight, A.V. began to dream of flying. He built dozens of models and in 1907 he won the " Daily Mail " prize for the best model aeroplane. As a result Roe began building his first full-sized machine.

The story of Roe's early attempts and his final outstanding successes are well known to every student of aviation. He fought against prejudice, ridicule and obstruction, and at Brooklands lived on a diet of dates, kippers and bacon largely. It takes that kind of diet to make one determined enough to get a new idea into the heads of most people. Successful pioneering flights were made, but finance became such a drag on aeroplane construction that Roe was faced with having to give up. On July 13th, 1909, Roe made his first flight of about 100 feet in his 9 h.p. triplane at Lea Marshes. The machine is now one of the historic exhibits in the South Kensington Museum. Before the end of the month Bleriot had made his famous cross-channel flight.

The financial assistance afforded by A. V.'s brother, H. V. Roe, enabled Roe to go on experimenting and building. The war of 1914-18 set the seal on all his endeavours. The famous 504 K was built in unprecedented numbers, new machines were designed, and the firm of A. V. Roe, Ltd., was thoroughly established. In 1928 A.V. sold out his interests and took over S. E. Saunders, Ltd., to make the now well-known firm of Saunders-Roe.

" The World of Wings and Things " abounds with reminiscences of famous aircraft pioneers, amusing, tragic, informative, recollections of enthusiastic pioneering days when there was a great spirit of adventure which now, alas, has been almost eliminated by the greater tentacles of finance. Unfortunately, in some ways, despite the protests of some in aviation, there is money in aeroplanes, and where there is money there is not much of the spiritual uplift which drives men on.

A.V. writes much from memory and people's memories are apt to differ. Short Brothers, for example, did not build Moore-Brabazon's machine of 1907, which crashed. Their first machine was built for Frank McClean and their second made later for Moore-Brabazon in which he won the prize offered by the " Daily Mail " for the first circular flight of one mile.

A considerable part of the book is devoted to the author's views on the world of to-day and to-morrow and his views on currency. They are the author's views, pertinaciously held, but many will not agree with them. His views on Hitler and Mussolini and the Jews may or may not be correct, but they must certainly be distasteful to the majority of people in this country. The author, at any rate, does not lack the courage required of the pioneer, but like many pioneers he spoils his case by over-statements which are not backed by documentary evidence.

NATURE PARADE.

Frank W. Lane. Jarrolds. 15/- net.

This is an excellent selection, extremely well illustrated, of unusual facts about the lives of wild animals and birds. Mr. Lane has delved deeply into the reports of naturalists from all over the world and classified the results of his painstaking research so that the ways of animals may quickly be studied from any point of view, from the ceaseless hunting for food to the endless fighting for existence.

Sectional headings, as food, toilet, sleep, leadership, strength, speed and locomotion, will give some idea of the variety and scope of the book. The strength of many animals is almost beyond belief, though there are many authenticated stories of the fighting strength of fishes and animals when cornered.

The book is packed with a series of remarkable photographs. " Nature Parade" can be recommended as an excellent present to anyone interested in nature study, for its astonishing variety and unusual selection.

QUADRILINGUAL AVIATION PHRASE BOOK (English, French, Spanish, German). By H. J. Day. Gale and Polden. 5/-.

In that delightful book, " Nymph Errant," the home-coming heroine greets her aunt with: " Comment allez-vous?" The old lady was vaguely conscious that she was being spoken to in a foreign language. " Bitte?" she said. " Wie geht es Ihnen?" said Evangeline. " Prego?" " Come stà?" " Why," said her aunt, " you're quite a linguist!"

Judged by this standard, Mr. H. J. Day is " quite a linguist." The unfortunate thing is that he therefore feels qualified to undertake the sole editorship of a technical phrase book. Dealing with one language only, his German errors range from joyous howlers like " Flugzeugbauer " (" aeroplane peasant ") for aircraft designer, " Regenscheiber " (" rain-pane ") for slide-rule (Rechenschieber), " Voll-Landung " (" complete landing ") for full load, " missweizender Kurs " (" bad wheat course ") for angle between magnetic meridian and line of flight, through lower fourth form grammar and spelling (" Bitte befreien Sie den Flieger, *den ist verlezt*," three separate mistakes!), slovenly definitions (Höhenkrankheit," given as " air sickness " is actually " altitude sickness ") and coined words (" Lufteingang," " Fluggastgeberin "), to such minor details as misuse or omission of the umlaut (" Luftdrück," " atmosphärische, Störungen," with its quaint comma), misreading of Gothic print (" Schleppfeil " for " Schleppseil "; " Farnung "—ferns—for " Tarnung "—camouflage), and what may charitably be classed as typist's errors (" Bremsklatte "—a confusion between " Bremslatte "—air brake—and " Bremsklappe "—braking flap). " Waagerschtflug " (for " Waagerechtflug ") seems to have been taken down phonetically from a Bavarian. Under the letter " A " alone, a German engineer of our acquaintance found 45 major and 36 minor mistakes.

French students can amuse themselves chasing errant accents (" bicille ") and discordant adjectives (" bottines fourrés "). The Spanish is full of gaps, and —oh, Mr. Day!—need you write, in your own language, " Heliocopter?"

The advertisement of this book recommends it to R.A.F. men taking interpretership examinations; to these, and to serious technical translators, we would suggest accepting it with the " ? " which the author ingenuously affixes to some of the terms that he himself suspects. In its present form, it will be of use to any pilot making a forced landing abroad, even if it does lead him to announce that he has broken his toy rattle (*Klapper*), when he thinks he is referring to his flaps (*Klappen*). A slightly wrong phrase is at least preferable to the time-honoured method of drawing pieces of an aeroplane on an envelope and holding up the appropriate number of fingers.

In his foreword Mr. Day naïvely remarks: " Those who have been privileged to obtain access to the first draft of the book found it of extreme use in catering for the many technical terms included in the test papers set by the Civil Service Commissioners."

And then they say the British are poor linguists!

The idea of the book is excellent. We would advise Mr. Day to obtain the collaboration of three pilot-engineers—a Frenchman, a German and a Spaniard—and to re-issue his work, in its present handy form, when they have finished blue-pencilling it. They will want one blue pencil each, at least!

THE ROYAL AERONAUTICAL SOCIETY

WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS.

MONTHLY NOTICES

FEBRUARY, 1940.

Office Hours.

The office hours will be from 9.30 a.m. to 5 p.m. from Monday to Friday and from 9.30 a.m. to 12.30 p.m. on Saturdays. The Library will be open during office hours and also on Saturday afternoons from 2 p.m. to 5 p.m. Members are specially invited to take the opportunity of attending on Saturday afternoons.

Annual General Meeting.

The Annual General Meeting of the Society will be held in the Society's Offices at 4, Hamilton Place, London, W.1, at the end of March. Notices will be sent to all voting members of the exact time and date.

Nominations for Council.

Attention is drawn to Rules 68-85 regulating the constitution of the Council, and in particular to Rules 79 and 81, which read as follows:—

RULE 79.—One half of the Council (excluding the President and the Immediate Past-President if a Member of Council) shall retire annually. The members who shall retire shall be those longest in office, except as provided in Rule 85. Retiring members of Council who have served two terms in succession (four years) shall not be eligible for re-election until the next annual election, when they will be eligible.

RULE 81.—Nominations of candidates for election to the Council must be received by the Secretary not less than twenty-one days before the Annual General Meeting, with an intimation in writing by the candidates that they are willing to serve. Nominations must be signed by one supporter and two seconders, who must each be entitled to vote in the R.Ae.S.I.

Under Rule 105 the Annual General Meeting is held at some convenient date before the end of March of each year, so that nominations must be received during the first week in March, and preferably by March 1st at the latest.

Members' Subscriptions.

Members are reminded that their subscriptions are due on January 1st, 1940. The Council hope that every member will make every effort to pay his subscription as early as possible. The rates are:—

	Home. £ s. d.	Abroad. £ s. d.
Founder Member	2 2 0	2 2 0
Fellow	4 4 0	3 3 0
Member	4 4 0	3 3 0
Associate Fellow	3 3 0	2 2 0
Associate Member	3 3 0	2 2 0
Associate	*2 2 0	*2 2 0
Graduate	2 2 0 (21-26 years)	
	2 12 6 (26-28 years)	
Student	1 1 0	1 1 0
Companion	2 2 0	2 2 0

* £1 1s. 0d. without JOURNAL.

Election of Members.

The following members were elected at a Meeting of Council:—

Fellows.—Frederick George Miles, Frank Nixon (from Associate Fellow)

Associate Fellows.—Eric Sydney Allwright (from Student), William Gardner Campbell, Robert Kelman Crowe, Douglas Alexander Fairnie, Robert Hogarth Douglas Forbes (from Student), Vishnu Madhav Ghatage (from Companion), Maurice Green (Thesis), George Henry Holdorf, Frank Holliday (from Associate), Harold Henry Hopkins (from Student), Frank Howarth, Harold Dickenson Jackson, Edward Loveless (from Graduate), Francis Charles Ivor Marchant, Basil Gervase Markham, Elwyn Ivo Banks Marples, Bernard Sidney Massey, Kenneth Holloway Matthews, David Ramsay Milne (from Student), Harry Frederick Rodgers, Daniel Seed, Robert George Simmons, William Stevenson, Christian Peter Wadsworth, Hugh Carlisle Wescombe, Paul White, Bernard Wilkinson (Thesis).

Associates.—Harry Herbert Aston, Charles Arthur Walter Ball, Albert James Cox, Clifford George Hayward, Frederick William Hughes, William Joseph Latty, Donald Lawler, Alfred James Mankelow, William Arthur Needs, Francis S. Organ, Reginald Frank Payne, Ernest George Pippin, William Pitson, David Edward Pritchett, John Pugh, Jack Reed, Frederick William Stallard, Alexander Thomas Eric Wanek, Bertram Woolcott.

Graduates.—John George Bradley, John Chapman, Gwilym John Cotroceni Davies, Kenneth Roy Davies (from Student), George Guthrie Miller Fitzpatrick, David Anthony Cardnell Harper (from Student), Alfred Henry Higgs, David William Jones, Gwyn John Owen, David Maresco Pearce, Eaton Holroyd Robinson, Charles Douglas Moore Stewart, John Yeadon Tomlinson, Gerard Nunan Verver (from Student).

Students.—John Evelyn Clausen, Andrew William Crichton, Frank Frodin, William Alfred Hibbert, Donald Farley Sargisson, Graham Frederick Simpkin, Donald Stanley Stewart.

Companions.—Terence Noel Hughes, David MacLeish Smith.

Lecture Programme.

Arrangements are being made by the Royal Aeronautical Society to resume part of the Lecture Programme which was postponed on the outbreak of war. The giving of these lectures depends upon the war situation and the censorship among other things, and what arrangements are being made can only be made with these two points in view.

It is hoped to arrange definitely for four or five lectures. The first one on "Aircraft Production" will be given by Mr. H. J. Pollard, F.R.Ae.S., on Tuesday, March 12th, 1940, in the Institution of Electrical Engineers, at 6.0 p.m.

Sir Alan Cobham and Mr. Marcus Langley have provisionally agreed to give a joint lecture on "Flight Refuelling in the Air"; Mr. A. A. Hall on "Recent Theoretical and Experimental Work on Turbulence"; Wing Commander T. R. Cave-Browne-Cave on "Noise and Nuisance in Aircraft," at dates to be fixed. The Wilbur Wright Lecture will be delivered at the end of May.

Coventry Branch Scholarship.

The Coventry Branch has founded a Scholarship with the object of encouraging members of the Branch to become full members of the Society, and to provide funds for suitable candidates to complete their education in aeronautics to the required standard.

The first award has been made to Mr. Reginald Dennis Lowe.

Library.

Following the change of the headquarters of the Society to No. 4, Hamilton Place, it became possible for the first time in many years to organise the library on a sound basis.

The books are now classified on a system based primarily on the alphabetical plan given in the American Aeronautical Chamber of Commerce Year Book for 1919. This classification has the two great advantages of elasticity and precision, for new sections can be added with the existing framework without disturbing the rest. Furthermore, it takes no account of location, so that books can be moved from one shelf to another.

Under the system it is not only possible to classify all books so that they can be found quickly either by author or subject, but also pamphlets, papers and reports, so that everything which is in the library on a given subject may be quickly consulted. At present there has been classified over 5,000 books and reports in the library, all of which, save for a small percentage on general allied subjects, deal with aviation in one branch or another.

Although the library of the Society is one of the most outstanding aeronautical libraries in the world, there are many gaps in its collection of historical books, papers, handbooks, catalogues, and so on, of aeronautical events, and it is hoped that members will give the library first consideration when they are turning out their old aeronautical literature.

Leverhulme Research Fellowship, 1940.

Applications are invited for Fellowships and Grants in aid of research. The Fellowships or Grants are intended for senior workers who are prevented from carrying out research work by routine duties or pressure of other work. They are limited to British-born subjects normally resident in Great Britain. In exceptional circumstances the Trustees may waive the condition as to residence. Forms of application may be obtained from the Secretary, Dr. L. Haden Guest, Leverhulme Research Fellowships, Union House, St. Martin's-le-Grand, London, E.C.1. Applications must be received on or before March 1st, 1940. Awards will be announced in July and the Fellowships or Grants will date from September 1st, 1940.

Binding of Journals.

Arrangements have been made for Members' Journals to be bound at the special price of 4s. 6d. per volume for the current volume and 5s. 6d. for back volumes. Journals should be sent direct to the Lewes Press, Limited, Friars Walk, Lewes, Sussex, and a remittance to the Society.

Membership List.

In reply to a number of members it is not proposed at present to continue the publication of the List of Members: (1) Because of the very large number of changes of addresses since the outbreak of war, changes which are not, in most cases, permanent, and (2) because the publication of temporary war addresses may be a useful indication to the enemy of the situation of many of our factories.

Employment.

The Society is in close touch with the requirements of the Aircraft Industry for qualified men. Members of the Society who are not at present employed should write to the Secretary stating particulars of the kind of post they are looking for and their qualifications.

Acknowledgments.

The Council acknowledge with grateful thanks the gift of a set of Royal Aircraft Factory Standard Specifications (1914-16) from Lieut.-Colonel M. O'Gorman, Fellow; also of a number of books and pamphlets of historic interest from Mr. M. H. Volk, Fellow, and from Mr. H. R. Trost.

Additions to Library.

Ref.

J.b. 13.—India Meteorological Department. Scientific Notes, Vol. VIII, No. 83:—

On the Forecasting of Rain over South Bengal during the Nor'-wester Season, mid-March to mid-May. By A. K. Roy, Manager of Publications, Delhi. 1939. 6d.

UF.3.—Ministère de l'Air. Publications Scientifiques et Techniques:—

No. 151. Étude des Tourbillons Thermo-Convectifs dans les Liquides. By V. Volkovisky. Frs. 30.

No. 152. Recherches sur l'Activité de l'Huile de Ricin. By J. J. Trillat and P. Nardin. Frs. 15.

No. 153. Étude de quelques Problèmes relevant de la Théorie des Ailes. By Lucien Malavard. Frs. 35.

No. 154. Étude Thermique de l'Oxydation des Essences. By Mme. Dufour-Estradère. Frs. 15.

UH. 3.—Atti di Guidonia. Editoriale Aeronautica, Rome:—

No. 15. La Galleria Ultrasonora di Guidonia. By Antonio Ferri. Lire 3.

UH. 4.—R. Politecnica di Torino, Laboratorio di Aeronautica. Publications:

No. 122. Sulla determinazione dei Coefficienti aerodinamici che interessano la Stabilità del Velivolo. By C. Possio.

No. 123. Le Oscillazioni proprie di un Corpo rigido sostenuto elasticamente. By P. Cicala.

No. 124. Sugli Orizzonti artificiali. By L. Elia.

No. 125. Sulle Travi di Altezza variable. By P. Cicala.

No. 126. La Geometria delle Ruote dentate e le sue relazione coi problemi di Lavorazione, Lubrificazione e Resistenza. By M. Panetti.

No. 127. L'Azione aerodinamica su di una Superficie portante in Moto vario. By C. Possio.

No. 128. Sulla Determinazione del Proietto di Minima Resistenza d'Onda. By C. Ferrari.

No. 129. Campo di Velocità ed Onde superficiali prodotte dall'Urto e dall'Affondamento di un Corpo in un Fluido pesante con superficie libera a Pressione costante. By E. Lorenzelli.

No. 130. Sul Moto non stazionario di un Fluido compressibile. By C. Possio

UL. 3.—Institute of Physical and Chemical Research, Tokyo. Scientific Papers:—

No. 939. On the Shift of Intensity in N_2 Bands excited in Helium and Neon. By T. Takamine, T. Suga and Y. Tanaka.

V. 3/13.—Institution of Automobile Engineers: Proceedings, Vol. 33, Session 1938-39.

B.a. 75.—Napier Aero Engines. D. Napier and Sons. Abt. 1926. £1 1s. 0d.

B.a. 76.—Some Developments in Aircraft Design and Application during the War. By Lord Weir of Eastwood. N.E. Coast Institution of Engineers and Shipbuilders. 1919.

B.a. 77.—Erecting and Aligning 80 h.p. Avro Biplanes (Type 504). By A. V. Roe and Co. 1917. 1/6.

B.g. 68.—Types of British Aeroplanes. Air Ministry. 1918.

B.g. 69.—An Album of British Aircraft. "The Aeroplane." Abt. 1926. 2/6.

BB.b. 62.—H.B. 806. Handbook of Strength Calculations. By A. J. S. Pippard and J. L. Pritchard. Ministry of Munitions. 1918.

BB.c. 29.—H.B. 302. Handbook on Construction of Propellers. Ministry of Munitions. 1918.

BB.e. 14.—Blackburn. (Reprint from "Flight," Nov. 21, 1930.) Blackburn Aeroplane and Motor Co., Ltd. 1930.

BB.e. 15.—A Brief History of the Blackburn Aeroplane and Motor Co., Ltd. (1909-31), and North Sea Aerial and General Transport, Ltd. (1919-31). Blackburn Aeroplane and Motor Co., Ltd. 1931.

C.c. 10.—Ballooning and its Application to Kite Balloons. 11th (Revised) Edition. By Griffith Brewer. Air League of the British Empire. 1940. 1/-.

D.a.B. 44 and D.a.B. 45.—Civil Aviation: Annual Report of Progress, 1938. Department of Civil Aviation. H.M.S.O. 1939. 2/6. (Two copies.)

D.a.B. 46.—Reports of the Civil Aerial Transport Committee, with Appendices. H.M.S.O. 1918. 9d.

D.a.B. 47.—Half-Yearly Report on the Progress of Civil Aviation. Oct. 1, 1919, to March 31, 1920. H.M.S.O. 1920. 3d.

D.a.B. 48.—Half-Yearly Report on the Progress of Civil Aviation. April 1, 1920, to Sept. 30, 1920. H.M.S.O. 1920. 4d.

D.a.B. 49.—Convention Relating to International Air Navigation. (Cmd. 266.) Air Ministry. 1919.

D.b. 44.—The Future of Aerial Transport. (Reconstruction Problems, 34.) Ministry of Reconstruction. 1919.

D.f. 4.—Safety in the Operation of Air Transportation. By Jerome Lederer. Norwich University, Northfields, Vermont (U.S.A.). 1939.

E.b. 33.—Wave Transmission: A New Method of Transmitting Power. By G. Constantinesco. (Privately printed.) 1916.

E.f. 53.—Aircraft: Instructions for Care and Maintenance. Royal Naval Air Service. Air Dept. 1915.

E.f. 54.—Royal Naval Air Service: Instructions for Inspecting Officers. Air Dept. 1916.

EE.a. 52.—Notes on the Care and Maintenance of the 105/115 h.p. "Cirrus Hermes" Aero Engine. Cirrus Aero Engines. 1930.

G.a. 27.—Manual on Cutting of Metals. (Single-Point Lathe Tools.) American Society of Mechanical Engineers. 1939. $5.00.

G.b. 8.—R.A.F. Standard Material Specifications, 1914-16. Royal Aircraft Factory.

Q.b. 48.—Association of Special Libraries and Information Bureau: Report of Proceedings of the Sixteenth Conference, 1939. A.S.L.I.B., 1939. 5/-.

RR. 91.—Principles of Flight. By Algernon E. Berriman. "Flight" Publishing Co. 1913.

S.a. 74.—Flying Section 17. Hauptmann Heydemarck. The Ace Publishing Co. 3/6.

T.c. 24.—The Andrée Diaries, S. A. Andrée, Nils Strindberg and K. Fraenkel. (Edited by the Swedish Society of Anthropology and Geography.) John Lane (The Bodley Head). 1931.

Forthcoming Events.

Tuesday, March 12th, at 6 p.m.—Lecture by Mr. H. J. Pollard, F.R.Ae.S., on "Aircraft Production," in the Lecture Hall of the *Institution of Electrical Engineers*, Savoy Place, Victoria Embankment, S.W.1.

Coventry Branch.

Tuesday, February 13th.—R.A.F. Training Films on "Meteorology."
Tuesday, March 12th.—"Optical Methods of Measuring, as Applied to the Aircraft Industry," by Messrs. Clarke and Hancock.

J. LAURENCE PRITCHARD, *Secretary and Editor.*

The 643rd Lecture read before the Royal Aeronautical Society since its foundation on January 12th, 1866.

PROCEEDINGS.

A meeting of the Royal Aeronautical Society was held in the Lecture Hall of the Institution of Mechanical Engineers at Storey's Gate, St. James's Park, London, S.W.1, on Thursday, February 16th, 1939, when a paper on "Some Factors Controlling the Development of Electrical Ignition of Aero Engines," by Dr. G. E. Bairsto, D.Sc., D.Eng., M.I.E.E., F.Inst.P., was read and discussed.

In the chair, Mr. A. H. R. Fedden, President of the Society.

The PRESIDENT: A great many years had elapsed since a paper had been presented to the Society on the subject of ignition in internal combustion engines, and the Society was privileged in securing a paper on that subject by so eminent an authority. For a great many years, Dr. Bairsto had been in charge of the Electrical and Ignition Research Department at the R.A.E. at Farnborough. At the beginning of the last war they in this country had been in a most difficult position, inasmuch as all their ignition apparatus had been obtained formerly from the Continent. During the early days of that war, Dr. Bairsto had put in some really good work, and ever since then he had been developing the ignition side of engines. Of course, the problems of ignition had altered greatly. Highly supercharged engines had been developed and there were considerably higher outputs from the high octane fuels, and they had been up against the difficulties of the magneto and the sparking plug. It was essential, therefore, that the subject of ignition should be reviewed.

SOME FACTORS CONTROLLING THE DEVELOPMENT OF ELECTRICAL IGNITION OF AERO ENGINES.

By G. E. BAIRSTO, D.Sc., D.Eng., M.I.E.E., F.Inst.P.

INTRODUCTION.

The conditions in which the various parts of the ignition system of aero engines have to operate have during recent times become much more onerous than hitherto. Many of the developments which have occurred in modern engines have caused the emergence of new problems so far as the ignition system is concerned, and have made older problems which had been only partially solved, even more difficult. This paper presents a review of some of the more important factors which are involved, an account of how the problems which have arisen have been solved, and indications given of limitations which still exist in various directions.

1. CONDITIONS IN WHICH THE IGNITION SYSTEM HAS TO OPERATE.

The essential conditions which have to be met are:—

(*a*) A regular succession of sparks is required, tuned synchronously with respect to the position of the piston in the cylinder.

(*b*) The sparks occur between electrodes in the spark plug set at gaps of the order of 0.012in. to 0.015in. which may increase to 0.020in. due to erosion after a period of use in the engine. The corresponding voltages vary from 5,000 to 8,000.

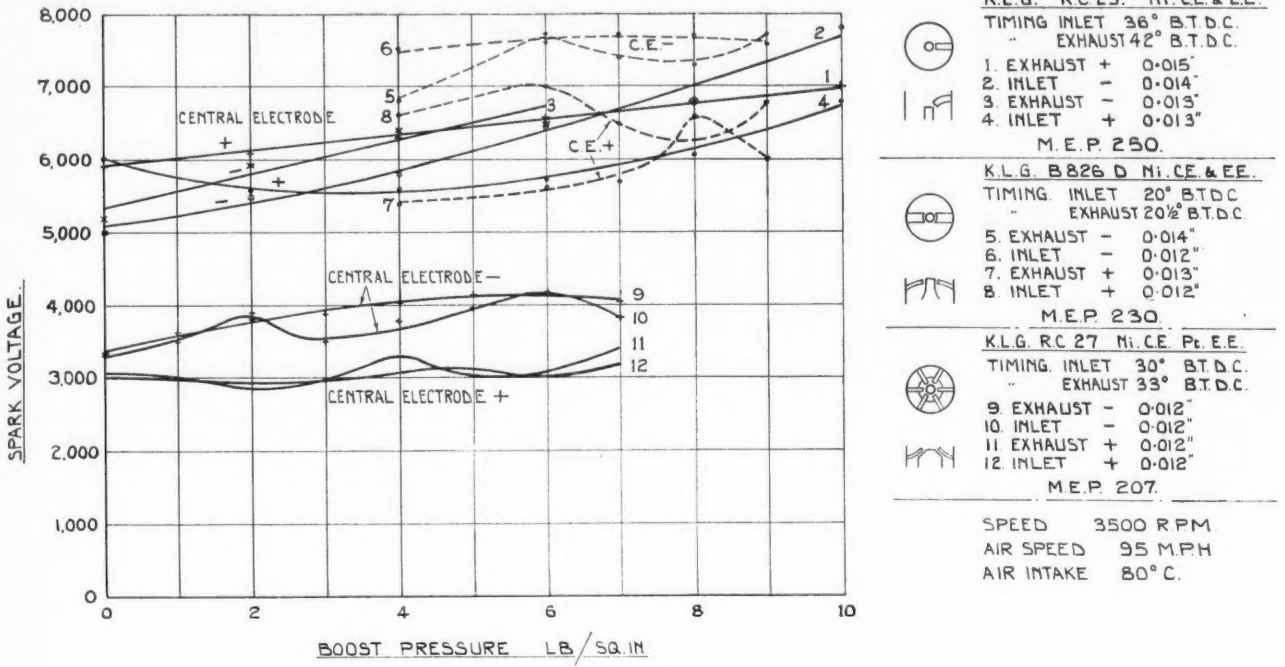

FIG. 1.

Sparking plug voltages measured on two-cylinder Dagger unit.

The following data have been obtained from a Kestrel X engine (unsupercharged), 7 : 1 compression ratio, 87 octane fuel.

Normal running :—0.13in. plug gaps, 4,500 to 4,800 volts, depending upon type and material of central electrode

0.25in. plug gaps, 5,300 to 7,800 volts.

Cold starting :—0.13in. plug gap, 5,000 to 7,000 volts.

Fig. 1 shows a series of tests taken on a Dagger engine at different boost pressures and with different types of plug electrodes.

(*c*) The sparks so formed must be capable of giving effective ignition of the petrol-air mixtures which are normally used.

The amount of energy required to give effective ignition is fortunately very small and considerably less than is provided by any known type of ignition system.

Fig. 2 shows the results of experiments made by Paterson and Campbell (1) on the minimum energy required to fire a petrol and air mixture at various voltages. It will be seen that provided the voltage is in excess of 4,500, the energy is only of the order of 0.007 joule per spark for a weak mixture, and 0.004 joule per spark for a rich one. With increase of voltage the required energy falls very rapidly. These figures are small compared with the energy of the spark obtained from most magnetos and ignition systems, which is about 0.02 to 0.06 joules per spark.

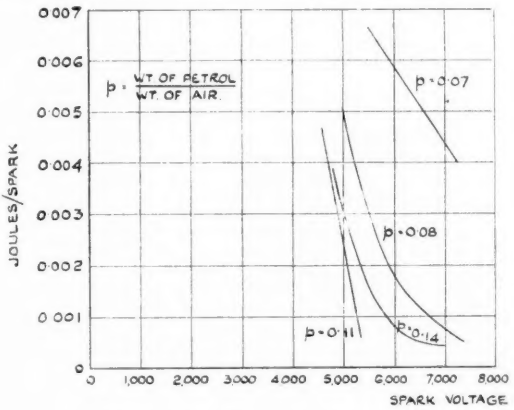

FIG. 2.

Showing the variation of minimum spark energy for ignition and the voltage and the mixture strength. (Paterson and Campbell.)

(*d*) The whole system must operate in an ambient temperature considerably in excess of normal air temperatures. Temperatures in the engine bay of high duty engines have been measured as high as 72°C., the temperature of the carcase of magnetos up to 82°C., and the temperatures of cables near exhaust pipes up to 150°C.

(*e*) It must operate perfectly at the reduced air densities corresponding to altitudes reaching 30,000 to 50,000 feet. For example at :—

TABLE I.

Altitude (I.C.A.N.)	Air density compared with that at ground level.
20,000	0.53
30,000	0.36
40,000	0.23
50,000	0.15

(*f*) It must, particularly when starting, cope with a wide range of atmospheric humidity. It has also to cope with leakage on the H.T. parts of the system, especially the sparking plug.

(*g*) It must operate in such a way as not to cause interference to the radio receiver used on the aircraft. The whole ignition system must be electrostatically screened; this superimposes a capacity load on the ignition generator of between 150 to 250 micro-microfarads in a typical aero engine which tends to lower the available voltage.

(*h*) It should operate without attention for at least the period between major overhauls of engines, say 400 to 500 hours.

The most important single factor which has made conditions so difficult to meet is the use of fuels of high octane number, 87 in present day engines, and 100 in experimental types. The higher compression ratios and boost pressures involve a large increase in the mean effective pressure and therefore in the voltage which must be available at the spark plug electrodes.

(*i*) It shall be fireproof when working in an explosive mixture of petrol and air.

The use of fuels of high octane value also involves, because of their high lead content, increasing tendency for conducting deposits to be formed on the sparking plug insulators.

Coupled with the increase of mean effective pressures, there has also been a large increase in the temperature of the external surfaces of the engine. This has caused difficulties, chiefly of provision of suitable materials in magnetos, sparking plug fittings and cables. The increased power/volume ratio and the need for closer cowling of the engine in modern high speed engines are also factors which have still further enhanced the temperatures in which all parts of the ignition system operate. Temperatures of the order of 90°C. for the faces of the attachments of magnetos have been measured on some engines.

Closer and more refined cowling of the engine has also made the demand for smaller magnetos, or at least of magnetos of more accommodating shape so that they can be disposed to the best advantage.

Increasing crankshaft speeds, and the adoption of large numbers of cylinders, have involved a large increase in the maximum speeds of magnetos, and superimposed on this is the demand for the engine and the magneto to meet the enhanced speeds, over and above the normal maximum speeds, which occur on power dives of the aircraft.

Increased speeds, increased compression ratios, increased velocities of inlet of the fuel mixture to the cylinders, and consequential increased turbulence of the mixture have all increased the erosion of the sparking plug electrodes. Increased turbulence has also tended to increase the plug voltage.

The increase of compression pressures and boost pressures has led to increased tendency to misfiring at altitudes of 30,000 feet and over, because of spark discharges within the magneto in preference to the sparking plug.

The effect of these various factors will now be considered in their effect on the magneto, or other spark producing device, the sparking plug and its associated fittings, the H.T. cables and the screening of the H.T. system.

2. The Magneto.

It is not the purpose of this paper to consider the basic theory of the magneto and certain theoretical details only will be referred to in so far as they are necessary to elucidate the practical points at issue.

Every magneto or coil ignition system produces a series of transient discharges having a large decrement. The transient is caused by a sudden disturbance in two coupled electrical circuits, each having inductance, capacity and resistance. Being therefore produced in a system having two degrees of freedom, the transient is composed of the superposition of two components each having different

amplitudes and frequencies. Fig. 3 shows a typical voltage-time curve of such a transient produced by a modern magneto without a spark occurring. It is a wave which after five or six positive and negative humps has rapidly attenuated to zero. The voltage rises to a maximum of approximately 18,000 volts. The spark occurs at some point between the origin of the transient and the crest of the first hump and thereafter the rest of the discharge is useless so far as the ignition process is concerned when the engine is running normally. This tran-

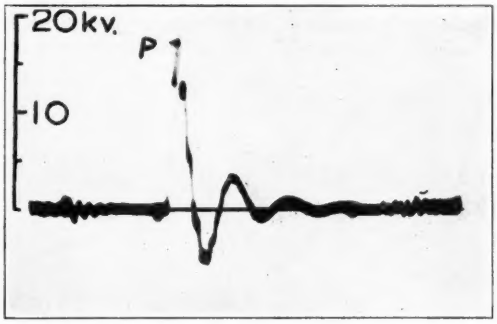

FIG. 3.
With plain cables.

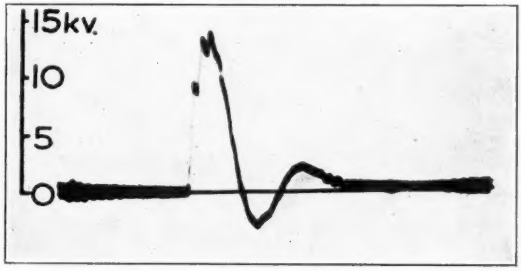

FIG. 4.
With 6ft. length of braided cable.

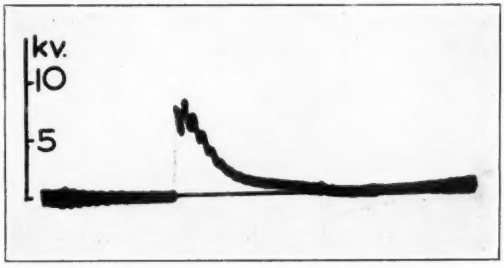

FIG. 5.
With 6ft. length of braided cable and a leakage load of 0.2 megohms.
Secondary voltage curves of magneto on open circuit.

sient has, however, to be of such a nature that it is not seriously affected by there being a load superimposed on the magneto of a capacity of 200 micro-microfarads and a shunt resistance of 200,000 ohms. (The standard conditions laid down for type tests of magnetos, simulating the capacity of screened cables and plug leakage.) Fig. 4 shows how the transient is affected by such a capacity load. The peak voltage is reduced somewhat, the frequency is reduced, and the decrement of the oscillation is considerably increased. Fig. 5 shows how the transient is affected by the addition of both capacity load and resistance load. We now have a pulse which dies down to zero without any negative portion below the time axis.

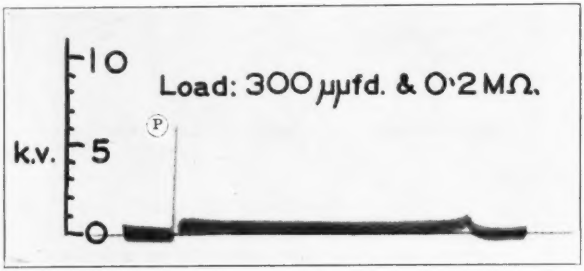

FIG. 6.

Normal test gap voltage with undisturbed gaps, 6,000 v. peak. Showing a continuous arc.

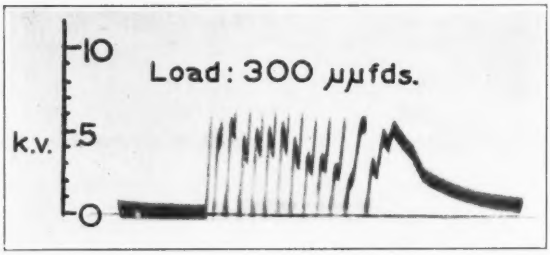

FIG. 7.

Test gap voltage, 6,000 v. peak. With strong air blast on gap. Showing absence of arc.

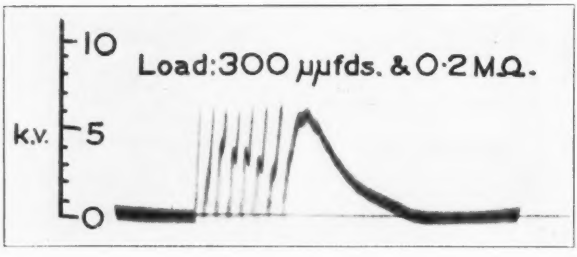

FIG. 8.

Test gap voltage, 6,000 v. peak. With strong air blast on gap. Showing absence of arc.

Passing now to what happens when the magneto is allowed to discharge through a spark gap, Fig. 6 shows what occurs when the spark gap is a test bench gap in air, set to discharge to 6,000 volts. The spark which occurs at point *P* arrests the normal development of the transient. There is a sudden drop of voltage, so sudden in the oscillogram depicted that the photographic film has not recorded it, followed by a negative portion and a quick dying out. If the spark gap is blown upon with a vigorous air blast we have the effect shown in Fig. 7; the first spark discharge is followed by a number of other sparks each being blown out by the air blast. After the last of the series of sparks, the voltage-time curve follows the normal curve of dying down. Fig. 8 shows the effect of adding 250 micro-microfarads and 200,000 ohms shunt; there are fewer separate sparks. It will be noted that the peaks of the separate sparks are not very much lower in value than the first discharge.

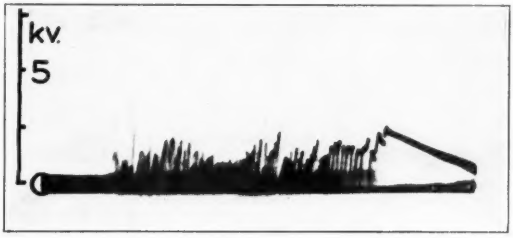

FIG. 9.
Exhaust, 0.012*in. gap.*

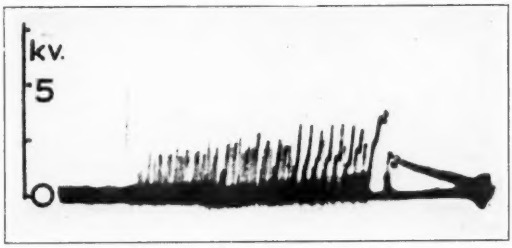

FIG. 10.
Inlet, 0.012*in. gap.*

When the magneto is used on an engine the results are even more interesting. Figs. 9 and 10 show the records taken with braided cables of 250 m.m.fds. capacity and plug gaps set at 0.012, the first curve was taken on an exhaust side plug, the second on the inlet side. We now have an initial spark discharge at a voltage of 5,000 volts, followed by a very large number of oscillations of voltage at a much lower value. If the plug gap is opened to the excessive amount of 0.030 we have the results shown in Figs. 11 and 12, the former being taken on the exhaust side and the latter on the inlet. The greatly reduced height of the peaks which follow the initial spark is due to the increase in temperature of the gases in the cylinder after the explosion.

(*a*) EFFECT OF ELECTRICAL LEAKAGE ON PERFORMANCE OF A MAGNETO.

From a large amount of evidence which has accumulated on mica plugs, it has been found that the electrical resistance of the plug falls frequently to as low as 200,000 ohms, largely due to infiltration of carbon deposits into the mica.

Plugs insulated with aluminium oxide give much better results on the average with fuels of 87 octane value, resistances of the order of 1,000,000 to 500,000 ohms being occasionally obtained, particularly when the plug is running at too cool a temperature. As regards the effect of the increased lead content of fuels of 100 octane value, the experience so far is rather meagre, but the tendency is for the resistance to be somewhat lower.

The reduction of the surface resistance on the other parts of the H.T. system has in the past given a certain amount of trouble, particularly with sparking plug fittings, imperfectly assembled, allowing moisture to penetrate. The introduction of a complete metallic screen over the whole system is of considerable help in preventing ingress of moisture.

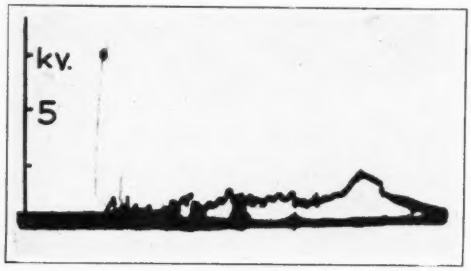

FIG. 11.

Exhaust, 0.030in. gap.

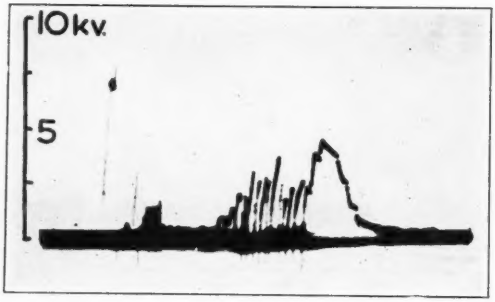

FIG. 12.

Inlet, 0.030in. gap.

Plug voltage curves on engine loaded with 6 feet of braided cable.

Fig. 13 shows a series of performance curves taken on some typical magnetos:—

A is a British 12-cylinder magneto of the four-spark per revolution type having a rotating magnet.

B is a German 16-cylinder magneto giving eight sparks per revolution having rotating inductors and single magnetic and electric circuits and double contact breaker.

C is another Continental 9-cylinder magneto giving four sparks per revolution having rotating magnets.

D is an R.A.E. design giving six sparks per revolution having rotating inductors.

The upper set of curves shows the voltage obtained at different speeds with no shunt resistance load, but with 200 m.m.fds. capacity in parallel. The middle set of curves are for a load of 500,000 ohms and the lower set for a load of 200,000 ohms, in addition to the capacity load.

The present Air Ministry schedule of type tests for magnetos (D.T.D. Spec. 2001) lays down that the magneto shall be capable of—

(*a*) Giving regular sparking at 9,000 volts, with 250 m.m.fds. and no resistance load, in the retarded position at 350 r.p.m.;

and (*b*) Giving regular sparking at 5,000 volts, with 250 m.m.fds. and shunted resistance of 200,000 ohms at a speed 25 per cent. in excess of that of the established maximum permissible r.p.m. of the engine.

As it is believed that the maximum future engine speeds, allowing for terminal dives, is not likely to exceed 5,000 r.p.m. it would appear from Fig. 13 that these conditions can be met for any future engine provided:—

(*a*) That engines having 16 or more cylinders are designed on a dual basis that is duplicated electrical circuits and contact breakers.

(*b*) That further work on fuels of octane value of 100 does not involve much increase in spark voltages.

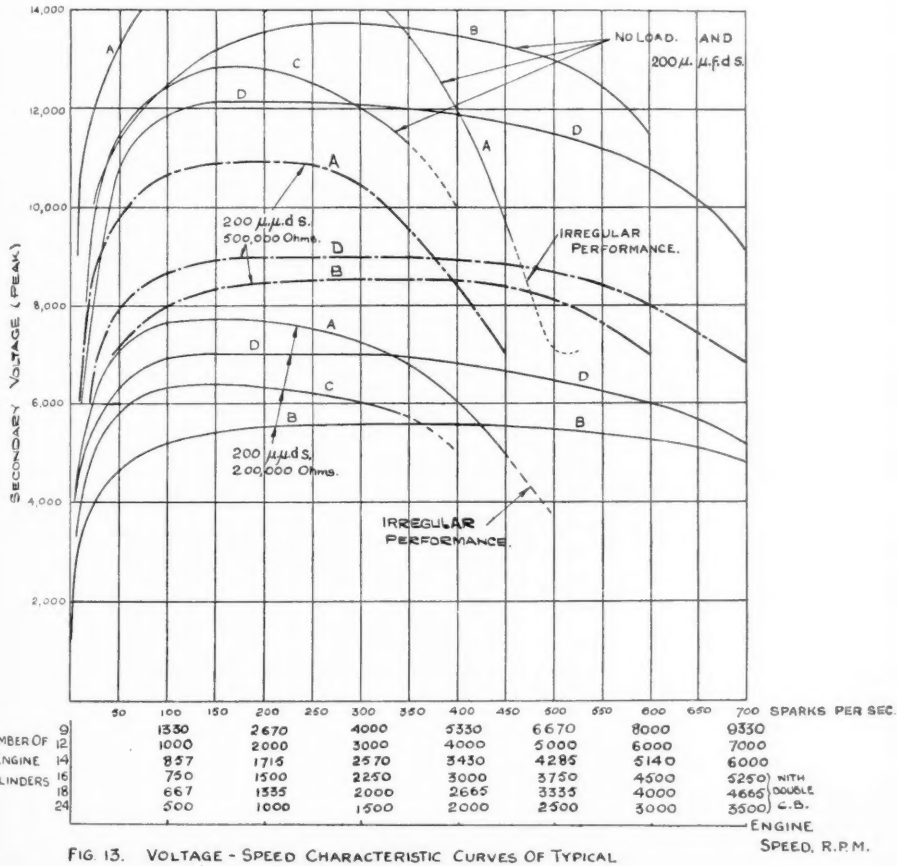

FIG. 13. VOLTAGE - SPEED CHARACTERISTIC CURVES OF TYPICAL MAGNETOS UNDER VARIOUS CONDITIONS OF LOAD.

That the second assumption is most likely to be invalidated is shown by a study of Fig. 1. Whilst something can be done to produce designs of plugs with lower spark voltages than the ones shown there, it is considered that there is a need for laying down new conditions for the case of magnetos to be used on engines running on 100 octane fuel. The suggested basis is 7,500 volts at 300,000 ohms. To attain this performance improvement in design is necessary.

As regards reliability under prolonged running, magnetos are available which can give between 350 and 400 sparks per second with a single contact breaker for periods of 500 hours, but more development work is necessary before a fully reliable performance is obtainable up to 500 sparks per second which would be necessary in order to obtain a 12-cylinder engine speed at 5,000 r.p.m. The factor limiting the reliability is the capability of the contact breaker meeting these high speeds, and the wear of the parts causing variations in the timing.

It is desirable to see what the possibilities are in improving the voltage performance under shunted resistance conditions. Theoretical discussions have been made by Bairsto (2), Darnell (3), Jones (4), Silsbee (5), and others. The first mentioned has shown that the secondary voltage E_s when the leak resistance R is large is given approximately by the expression :—

$$E_s = [\ \{\ (M+L_1)\ I_0 R\ \}\ /\ \{\ L_1+L_2+M\ \}\ ]\ [\epsilon^{-\{\ (R+R_2)/L_2\ \}\ (\pi/q)} + \epsilon^{-\{\ (R+R_2)/L_1\ \}\ (\pi/q)}]$$

where M = mutual inductance of the windings.
L_1 = primary inductance.
L_2 = secondary inductance.
$q = \sqrt{(1/L_1C_1)}$.
R_2 = secondary resistance at frequency $q/2\pi$.
C_1 = primary capacity.
I_0 = primary current at moment of " break."

In order to obtain the maximum voltage a close consideration has to be given to the inter-relationship between the various quantities which are involved so that the optimum value of each can be selected. For example, it has been shown (6) that there is an optimum number of secondary turns on any given magneto which gives the best performance. Many present day magnetos carry far more secondary turns than are desirable.

The most desirable proportioning of the coils on the magneto is bound up with the shape and disposition of the magnetic system and much work remains to be done in adjusting the electric and magnetic systems of the magneto to one another so as to achieve the best results.

(*b*) Effect of Reduced Available Space for Installation of Magnetos.

Three methods of dealing with this problem are available. First, the magneto distributor can be detached from the voltage generating part of the magneto and be assembled on the camshaft. This detachment inevitably means some increase in weight in structural parts of the engine, extra driving connections and cables, but in some engines has been found absolutely necessary.

Secondly, the use of recently developed magnetic alloys has enabled the magnetic system and therefore the surrounding structures to be reduced considerably. The amount of magnetic material used in the magnet is approximately inversely proportional to the product B.H. of the magnetisation curve of the magnet (7). The following table gives the values of this product for certain available materials :—

Table II.

Type of steel.	(B.H.) max.
6 per cent. tungsten	250,000
15 per cent. Co, 10 per cent. Cr	620,000
35 per cent. Co	1,000,000
Alni (Ni 25 to 30 per cent., Al 10 to 15 per cent.) ...	1,250,000
Alnico (Ni 18 per cent., Al 10 per cent., Cu 6 per cent., Co 12 per cent.)	1,700,000

The use of the Alni and Alnico alloys had revolutionised the possibilities in magneto design, but much has to be done yet to exploit these possibilities fully.

The third method of reducing the size of the ignition generator equipment is to combine the two units which are necessary to obtain dual ignition in such a way that only one driving shaft is used for both systems. By this means a magnetic system more or less common to both ignition generator units can be provided, but in such a way that the two electrical systems, *i.e.*, the L.T. and H.T. circuits are completely separated and non-interfering. This secures in effect nearly complete duality, the only element the failure of which entails risk of both sets of plugs failing simultaneously is the driving shaft, a risk which should be very remote. This assumes, however, that the two contact breaker mechanisms which are required for the two ignition systems can be designed in such a way, that although they are driven from the single driving shaft, failure of either will not adversely affect the other, a problem which is not a very difficult one.

Figs. 14 and 15 show ways in which this can be done. In the first figure (8) is depicted a magneto having two longitudinally arranged magnets with pole shoes at each end. In between the four-pole shoes is a shaft on which is mounted two inductors, each having three arms and polar extensions. The two sets of inductors are disposed circumferentially so that in any given position of the inductors with respect to the driving axis, alternative arms are of opposite polarity. Disposed between the two opposing pairs of pole shoes are two armature cores at 180° apart to which are attached the usual extensions for transmission of the magnetic flux from rotating inductor. In this way each " break " of the magnetic flux results in the generation of two simultaneous sparks and six such double sparks are created per revolution.

Fig. 15 shows another scheme (9) in which a six-armed spider rotates between the polar extension of two magnets disposed on each side of the magneto, with their polar axes vertical. Two armature cores bridge the gaps between the other poles of the magneto. In this way six double sparks are produced per revolution.

(*c*) Effect of Temperature.

The air temperature in which the ignition system has to operate has raised difficulties in a number of ways and the conditions which have now to be met by magnetos which are approved for service use in this country are as follows:—

> " Voltage characteristics and shunt resistance tests will be made. . . . The apparatus will then be placed in a closed box containing dry air at a temperature of 65°C. with the base or flange of the apparatus raised to a temperature of 85°C., and run under the conditions of endurance tests for 24 hours. Whilst still in the box and with the temperature maintained, voltage characteristics and shunt resistance tests . . . will be made. The reduction in spark voltage at any point in the speed range should not exceed 10 per cent. of the previous value. The spark voltage at the established slow speed test speed shall not be less than 5,000 volts when the H.T. circuit is shunted with a resistance of 200,000 ohms."

In practice these tests have not been found difficult to meet, the percentage figure referred to is usually not more than 7 per cent.

The effect of the temperatures referred to on the moulded insulation, which is used in such parts as distributor, distributor rotor, and coil insulation, is important. We have, broadly speaking, two classes of materials available, the loaded hard rubbers or stabilites, and the synthetic resins. The first class is electrically by far the better, but suffers from having too low a softening temperature. It is, however, practically immune from liability to " tracking," *i.e.*, the formation on the surface by high voltage stress of surface discharge paths exhibiting a carbonised track of low electrical resistance and low electric strength. The loaded hard rubber group suffers from the disadvantage that many of such materials

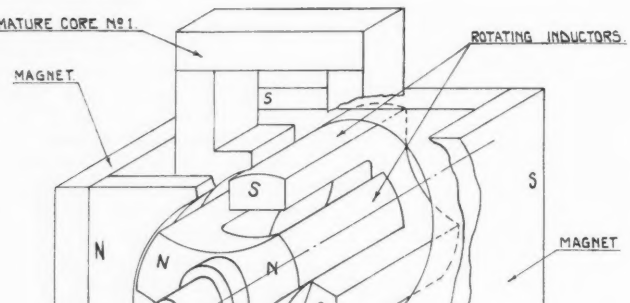

FIG. 14 DUAL 6 BREAK MAGNETO (G.E.B)

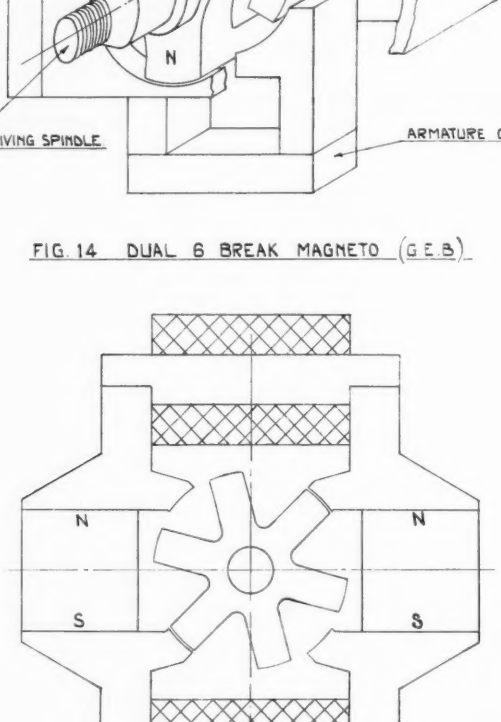

FIG. 15 DUAL 6-BREAK MAGNETO (BOSCH)

contract with prolonged exposure to moderate temperature, and the effect is more enhanced when the material is subjected to vibration.

The second class is electrically not as good as the first class, but the best of them have adequate electric strength for most normal designs. They suffer, however, from " tracking." They have the advantage that a much lighter distributor can be moulded in them than is possible with the stabilites, and their heat resisting properties are adequate.

Neither type of material is therefore all that is required, but by using somewhat large factors of safety, either can be used for the several purposes to which they are put. The tendency is to prefer the stabilites on account of the insidious nature of the " tracking " characteristics of the synthetic resins, a phenomenon the cause of which is not very well understood. Improvements have recently taken place in the urea group of the synthetic resins and it would appear that ultimately we may get in that class the all-round better material which is desired.

Another point of considerable importance is the effect of increased temperature on the lubrication of the bearings, trouble having been experienced in some of the latest designs of engines due to failure of lubrication. The trouble is common to generators and other accessories driven from the engine and further experimental work is required to evolve reliable lubrication schemes which will meet the ideal put before us of no maintenance for periods of 500 hours between overhaul.

(*d*) Effect of Reduced Density.

When an ignition system operates in the rarefied air of high altitudes, a number of interesting phenomena occur which increase considerably the stringency of the working conditions compared with those of ground level conditions.

Whenever the electric stress at a point of a conductor exceeds a certain value, the air at that point can no longer remain an insulator. If two parallel plates with well rounded edges forms the electrode system then at ground level conditions, if the electric stress exceeds 27,000 volts/cm. a spark discharge will take place. As the air density decreases, so does the electrical breakdown strength, following the well-known Paschen's law:—

$$\text{Voltage} \times \text{pressure} = \text{constant},$$

$$\text{or } E_\delta = \delta E_o = \delta \cdot 27{,}000$$

where δ = relative density (air at N.T.P. = 1).

In the case of non-uniform fields, that is concentrated fields between points or edges, the law is more complicated (10)

$$E_\delta = 27{,}000 \{ 1 + 0.54/\sqrt{(R\delta)} \}$$

where R = radius of equivalent sphere in cm. (see Fig. 16).

Fig. 17 shows some curves computed from this formula.

When R is small, it is possible to obtain local breakdown of the air near the points of the conductor where the electric stress is strongest without complete breakdown across the whole field (Fig. 18). This is the well-known " corona " or " brush discharge " without spark.

A number of different kinds of effects result from these phenomena:—

1. There may be spark-over at reduced densities and to avoid this, the " air space factor " between the H.T. parts of the magneto and earth must be increased to prevent it, otherwise mis-firing at the sparking plugs will result.

This effect is illustrated in Fig. 19 which shows results of some actual tests on a particular engine which some time ago was mis-firing at high altitudes. The two lower curves show how the voltage required from the magneto to give regular firing at the sparking plug decreased as the altitude increased, the plug gaps being 0.013in. and 0.023in. respectively. The two upper curves are the voltage-altitude characteristics of the magneto. The curve *A* is that of the original magneto. It can be regarded as made up of two parts, the first covering the lower altitudes, shows that there is a particular discharge path to earth which

sparks over at 10,200 volts ground level conditions which sets an upper limit to the possible voltage which the magneto can give, although when the coil of the magneto was itself separated from the other H.T. parts of the magneto, it could give a voltage of approximately 14,000 volts. The second part of the curve covering the higher altitudes shows that this parallel path for spark-over has a falling characteristic in accordance with one or other of the curves shown in Fig. 17. This drop in voltage with increase of altitude was of such a shape that it crossed the lower plug-gap characteristic at 35,000 feet which was the limiting height for the engine with plug gaps of 0.013in.; above that height the alternative discharge path would short circuit the plugs and misfiring take place. With spark plugs which had been in use for some time (upper curve gap = 0.023in., the limiting height was 23,000 feet. By modifying the magneto so as to increase

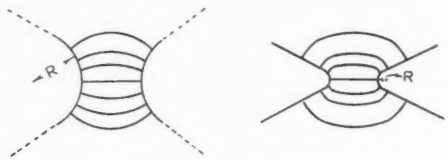

FIG. 16.

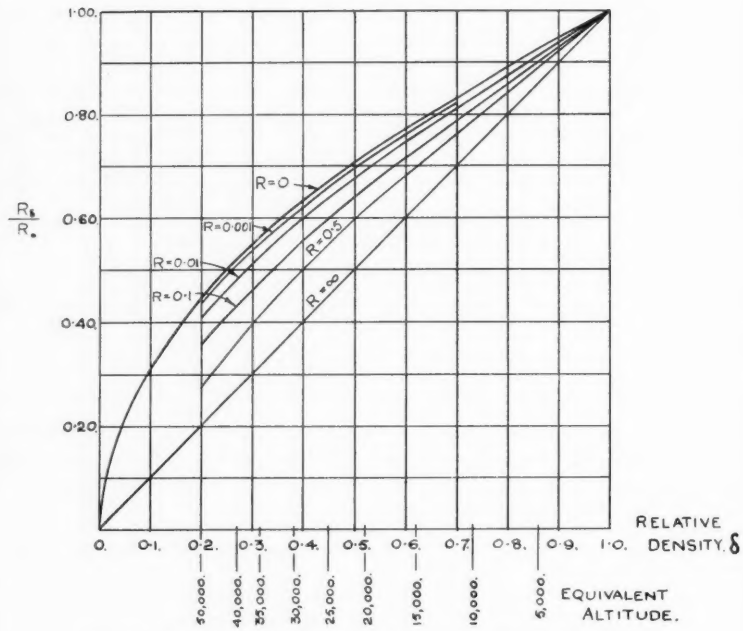

FIG. 17. SHEWING VARIATION OF ELECTRIC STRENGTH R_s OF AIR WITH AIR DENSITY AND RADIUS OF ELECTRODES. (CALCULATED FROM PEEK'S FORMULA)

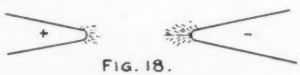

FIG. 18.

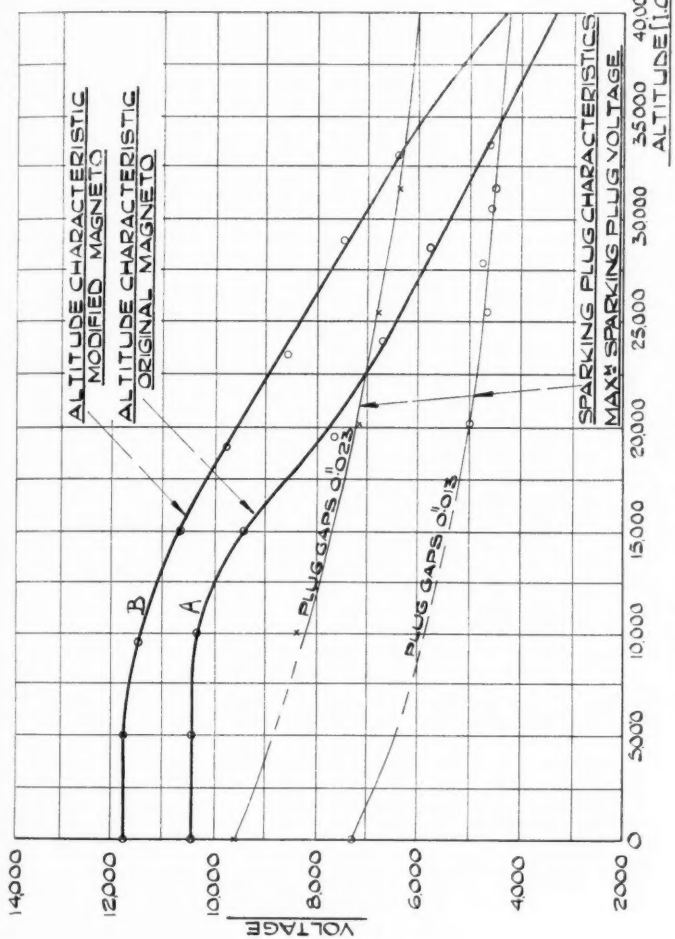

FIG. 19. SHEWING THE VARIATION WITH ALTITUDE OF THE SPARKING PLUG VOLTAGE IN AN ENGINE WITH THE VOLTAGE OF ALTERNATIVE PATHS IN MAGNETO

A.B. MAIN BRUSHES
1 TO 12 SEGMENTS
S.B. STARTING BRUSH.
R. ROTOR.
W. WEB BARRIER

FIG. 20. DIAGRAMMATIC REPRESENTATION OF A MAGNETO DISTRIBUTOR AND ITS ROTOR SHOWING THE ALTERNATIVE PATHS FOR SPARK-OVER.

the surface and the space breakdown factors, the magneto performance was raised to the upper curve. Then the maximum height with new plugs was 40,000 feet and with plugs with eroded gaps was 33,000 feet.

The standard reduced density test for R.A.F. magnetos is that regular sparking across standard test gaps set at 6,000 volts shall be obtained from all H.T. leads when the magneto is operated in an apparatus exhausted to a density equivalent to 45,000 feet.

Some indication of the different kinds of parallel paths which have to be considered and give appropriate space or surface safety factors can be seen in Fig. 20, which gives a diagrammatic view of a 12-cylinder semi-circular type of distributor with two rows of distributor segments. The possible alternative discharges are:—

(*a*) From the rotor brush in the distributor of the housing frame (Fig. 20*a*).
(*b*) From the rotor pick-up to the slow speed gear wheel hub (Fig. 20*b*).
(*c*) From the front rotor brush to an adjacent rear segment (Fig. 20*c*).
(*d*) From the rear rotor brush to adjacent front segment.
(*e*) From rotor brush to adjacent segment in line (Fig. 20*d*).
(*f*) Between segments in line (Fig. 20*e*).
(*g*) Between cable socket terminal in the distributor and the screen of the magneto (Fig. 20*f*).

Experience has shown that to meet the type tests conditions referred to above, these paths must be at least 20 m.m., and where the path is closely confined between neighbouring masses of insulating material, as in case *b* and *f* the path should be increased to at least 25 m.m.

2. The " Corona " discharge may be so severe that a serious fall of voltage performance may result at low air densities due to energy losses in the air and particularly in the windings of the H.T. coil. Fig. 21 shows the effect of reduced density on two types of coils on the same basic type of magneto, the tests being arranged so that the effect on the coil above was isolated, and the magneto performance limited to approximately 10,000 volts by shunting the primary winding. Curve *A* shows the effect on an early coil, a drop of voltage of 1,400 volts occurring between ground level and 30,000, curve *B* taken on a more recent coil shows a drop of only 1,000 volts at 37,000 feet. Very careful impregnation of the windings is essential so that no air is trapped in them. More work requires to be done at air densities equivalent to 40,000 to 50,000 feet.

3. Prolonged " corona " discharge may cause a progressive deterioration of the surface resistance of moulded insulation, due to the formation of nitrous and nitric acids and their chemical effect on the insulation. Such deteriorated surfaces may lead ultimately to " spark-over " because portions of the surface may become partially conducting.

Progressive deterioration of even more serious nature may take place inside the windings, thereby enhancing the power loss effect referred to in (2) above. and in some cases leads to electrical breakdown of the windings.

4. The chemical products of the corona discharge may have adverse effects on the lubrication of the bearings, the nitric acid and other products which are formed breaking down the oil or grease leading ultimately to disintegration of the bearings.

5. The presence of a moulded insulation surface itself near the H.T. conductor introduces another factor, since the nature of the surface has in some cases a profound effect on the properties of the discharge. For example, in the simple system of electrodes shown in Fig. 22, the surface discharge properties of the insulation *I* will affect the electrical spark-over voltage between *A* and *B*, and usually the resultant electrical breakdown strength of the combined system is less than that with the electrodes *A* and *B* insulated merely by air. A good quality ebonite has practically the same surface discharge voltage as that of the air itself between the electrodes. Certain kinds of loaded hard rubbers have

very low values compared with ebonite. Synthetic resin materials of good quality have an intermediate position. Materials such as vulcanised fibre and synthetic resin impregnated paper compounds are as a general rule poor.

6. An important effect has been discovered in behaviour of the spark between the rotor in the distributor and the fixed distributing segment. At very low

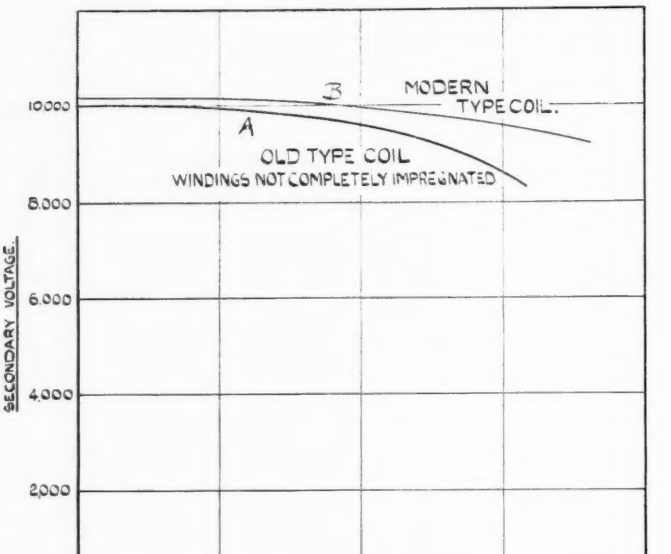

FIG.21. SHOWING THE DROP IN VOLTAGE DUE TO ARMATURE COIL OPERATING IN REDUCED AIR DENSITY.

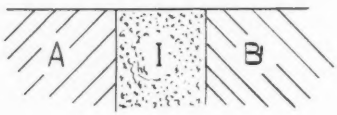

FIG.22.

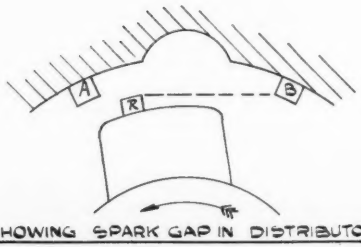

FIG.23. SHOWING SPARK GAP IN DISTRIBUTOR TO PRECEDING SEGMENT

densities it has been found that the spark sometimes prefers to jump back to the preceding segment B as shown in Fig. 23 instead of the proper one A. It seems to be due to the combination of two effects.

(*a*) The production of a highly ionised channel by the preceding discharge caused by the movement of the top of the rotor R drawing the ions round behind it.

(*b*) The reduction in the number of available ions in the space AR due to reduction of air density so that the chances of an ion being present near the electrodes to start the discharge is reduced. Confirmation of this effect was obtained by measurements of the variability in the spark voltage between R and A. The ratio between the maximum voltage of the small proportion of sparks which occur in the abnormal condition to the minimum voltage of the most favourable condition being about 1.7.

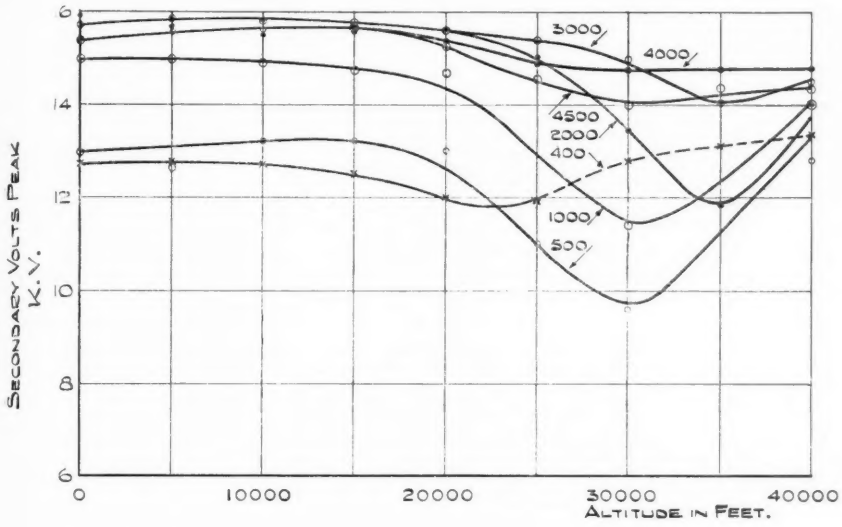

Fig. 24. Effect of Arcing at the Contact Breaker on the Voltage Performance at Various Altitudes

7. Since the formation of a spark or arc at the contact breaker point limits the maximum voltage available from the magnetos and the arcing occurs more readily at low densities, it follows that a magneto or coil system which is just operating near the permissible current carried at the points at " break " when working at ground levels may be unreliable to more or less extent at high altitude.

The results of some tests taken on the contact breaker of a 12-cylinder magneto of the rotating magneto type are given in Fig. 24. The contact breaker was subjected to reduced density conditions and used to " break " the current in another magneto running in synchronism and in correct phase relationship. This second magneto was running at ordinary ground level conditions of air pressure. It will be noted that at any magneto speed there is a dip in the curve of maximum available voltage. The higher the speed, the greater the altitude at which the dip occurs. It was noticed that the neighbourhood of the dip coincided with violent arcing at the contact breaker.

This effect is at present not of much practical importance, but if the engine pressures and boost pressures are increased much above present day conditions, then it will require careful consideration.

3. Coil Ignition Systems.

Considerable efforts have been made in the past three or four years both at engine constructors' and magneto manufacturers' works and at R.A.E. to develop coil ignition systems for particular application to aero engines. By a coil ignition system is meant one which has a separate coil with primary and secondary windings supplied from an accumulator which is fed by a generator. The claims made for such a system compared with an orthodox magneto are:—

(*a*) It avoids the necessity for the use of a hand starter magneto or other additional device for starting the engine, such as a booster coil.

(*b*) The driving mechanism can be of comparatively light construction, whereas the magneto drive may have to be of more robust construction to stand up to the torsional oscillations due to variations in the torque.

(*c*) The magneto and contact breaker form together a comparatively large unit which it may be difficult to accommodate conveniently, whereas the coil system can be installed in smaller separate units.

(*d*) It is possible to provide a consistent electrical performance over a wider range of advance and retard of movement.

(*e*) Where separate drives for the magneto and the distributor with contact breaker are used, an advance and retard mechanism must be provided for both drives, Servo operation is then necessary for the magneto. In a coil system, either battery or generator operated, only the distributor drive needs an advance-retard mechanism. There is thus a saving of weight.

(*f*) The coil system is easier to design than a magneto.

(*g*) The coil system is cheaper to manufacture than a magneto.

On the other hand the claims made on behalf of the magneto are:—

(*a*) If the aircraft electrical system is used as the source of current for the coil, all the associated circuits become an intense source of interference to the radio receiver because the high frequency disturbance produced by the sparks are also propagated from the primary windings and are impressed upon, and radiated from the wiring of the aircraft electrical circuits. The magnitude of this disturbance as actually determined by tests is prohibitive. If a separate supply system is used for the coil system the weight of accumulator and its charging generator becomes prohibitive especially, if to secure complete duality of the two ignition systems on the engine, the supply system has to be duplicated. Some mitigation of this heavy disadvantage is possible by hybrid schemes of the kind dealt with later on in this paper.

(*b*) The voltage performance of a coil system of the orthodox type under conditions of capacity load and shunt electrical resistance is not as good as that of a well designed magneto.

(*c*) The coil system cannot operate at as high sparking rates as a magneto.

(*d*) The reliability of a system composed of coil, generator and battery is not as great as that of a magneto.

(*e*) There is greater risk of fire on crash with a coil system.

Taking these points in more detail, the coil system definitely has the advantage over the magneto in respect of its better voltage performance at very low speeds, because, in these conditions, the primary voltage of the magneto and therefore the primary current are at their lowest. On the other hand, the coil system is

working at its best when run at low speeds. The period of " make " of the contact breaker being longest, the primary current is at its maximum. Therefore there is no need to use an auxiliary device to provide sparks when starting the engine.

As regard the question of robustness of the driving mechanism, the advantage in theory is with the coil system, but where a properly designed flexible drive is used there does not appear to be any evidence of the magneto drive being found deficient and the difference in weight is trifling.

Difficulties of accommodation of the complete magneto have arisen on several engines either because of limited available space, or of not being able to provide two magneto drives together with a drive for a generator as well as other auxiliaries. On the other hand, by separation of the distributors from the magnetos and mounting them on the camshaft axes, or by using a double magneto instead of two separate ones, there is considerable scope for using the available space to good advantage.

The difference in the electrical performance of the two systems calls for comments in several particulars. Fig. 25 shows the performance of a 12-volt coil system on which a considerable amount of work has been done and so far as the author is aware represents the best performance that has been obtained. It is extremely poor at high speeds, and even when designed for 24 volts, as shown on the next curve above, it does not compare favourably with the curves given by the best of the magnetos shown in Fig. 13. These comparisons apply whether made on no load or load. On the other hand, the volt-speed characteristic of an accumulator supplied system is much superior to a magneto at the lowest speeds.

The question which system is easier to design or cheaper to construct is in the aero engine case not so easily disposed of as in the case of the car engine, where, since a generator has to be provided in any case, and there are no other complications, the question is decided merely on that of the relative simplicity of a coil and its distributor compared with a magneto and the answer is obvious. But in applying a coil system to an aero engine, it has to be provided with its own generator, or for true duality with two generators which if they are to meet the wide range of speed conditions must be of a self-regulating type. Also as we shall see later, if the aircraft battery is used for starting purposes, then a special design of interference suppressor must be used. In the author's view it is therefore a very moot point which combination is the cheaper to manufacture.

The difficulties of interference from the coil system to the radio receiver has already been touched upon, and apart from leading to increased complexity in its elimination, it is also responsible for an increase in weight.

Reliability can be looked at from two aspects. The separation of the various units of a coil system, viz., coil, generator and accumulator entails more interconnecting cables than the magneto system. These either because of the possibility of disconnections or faults developing in the cables by abrasion or damage by bullets in military aircraft are rather liable to introduce an element of unreliability. (This does not apply to the scheme described later in Fig. 28, where two generators of a special self-regulating type are used with the hand starter.) Then again the primary supply in the magneto case is singularly free from elements which could cause interruption of the current, it has fixed windings and neither slip rings nor brushes, whereas the generator feeding the coil system has a rotating armature subject to centrifugal stresses, a commutator and brushes, both of which wear and deteriorate with time.

Finally, a certain amount of criticism has been made of coil and battery systems by those impressed by the unenviable record of a certain type of aircraft which during the Great War had a notoriously high proportion of fires on crash. The critics pointed out that the engine fitted to the aircraft was the only one used in the war which had coil and battery ignition. The coincidence may have been

PERMANENT MAGNET GENERATOR — LIMITED BY SPARKING AT C.B.
UPPER CURVES
200 Mfd LOAD
SELF REGULATING GENERATOR SYSTEM
24 VOLT BATTERY SYSTEM.
12 VOLT BATTERY SYSTEM
SELF REGULATING GENERATOR
24 VOLT BATTERY SYSTEM
12 VOLT BATTERY SYSTEM.
PERMANENT MAGNET GENERATOR
LOWER CURVES
LOAD: 200 Mfd
200,000 Ohms.
SECONDARY VOLTAGE.
SPARKS PER SEC.
ENGINE SPEED. R.P.M.
NUMBER OF ENGINE CYLINDERS
9 1330 2670 4000 5330 6670 8000 9330
12 1000 2000 3000 4000 5000 6000 7000
14 857 1715 2570 3430 4285 5140 6000
16 750 1500 2250 3000 3750 4500 5250
18 667 1335 2000 2665 3335 4000 4665
24 500 1000 1500 2000 2500 3000 3500

FIG. 25. VOLTAGE-SPEED CHARACTERISTIC CURVES OF COIL SYSTEM UNDER VARIOUS CONDITIONS OF LOAD.

fortuitous, but the technical point underlying the criticism is that simultaneously with the transient rise of voltage which occurs in the secondary of the magneto, there is also a primary transient of 600 to 1,000 volts peak, and if the primary circuit is broken at a point external to the coil, *i.e.*, the primary cables, the spark so caused is so powerful that it can fire an explosive mixture very easily. There is one type of coil system to which the above remarks do not apply, *i.e.*, where two generators of the special self-regulating type referred to later are used and the battery used for starting, after which it is switched off.

It would appear from the above considerations that the case for the coil system is based chiefly on matters of expediency and known difficulties in providing room for the ignition gear.

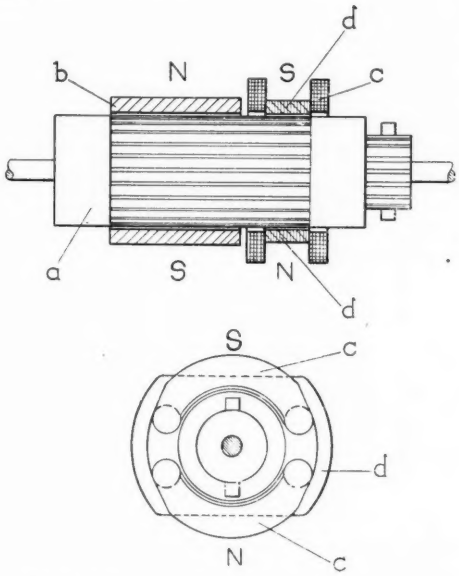

FIG. 26. SELF REGULATING GENERATOR FOR USE WITH COIL SYSTEM. (DEBENHAM)

(*a*) Development of Specialised Coil Systems.

As it is not possible to use current drawn directly from the aircraft accumulator on account of the ignition interference to R/T equipment, a scheme was devised by West (11) in which the coil is supplied by current from the battery while the engine is being started. In the normal running of the engine, the coil is fed from an engine-driven generator different from that by which the battery is charged, the change-over being made automatically by a relay which also disconnects both poles of the battery from the ignition circuits. Considerable work has been done on this scheme by Messrs. Rolls-Royce and R.A.E. in collaboration. The difficulties which had to be surmounted were:—

(*a*) The production of a design of relay which had the minimum capacity-coupling for H.F. oscillations between the broken contacts, so that interference from the coil side did not influence the circuits attached to the battery. The problem was ultimately solved, but the change-over speed could not be reduced below about an engine speed of approximately 800 r.p.m.

(*b*) The design of a generator which could meet the extreme range of speed required. The conditions which have to be met are first, at the " ticking-over " speed on the aerodrome the ignition system must not cause interference to receivers on near-by aircraft, or to the ground receiver, and therefore must be disconnected from the battery; secondly, that of high speed dives; and thirdly, it is imperative that interference should not occur even at the lowest possible engine flight speeds so that V.S.W. radio may be available for blind landing, or when approaching an aerodrome throttled down.

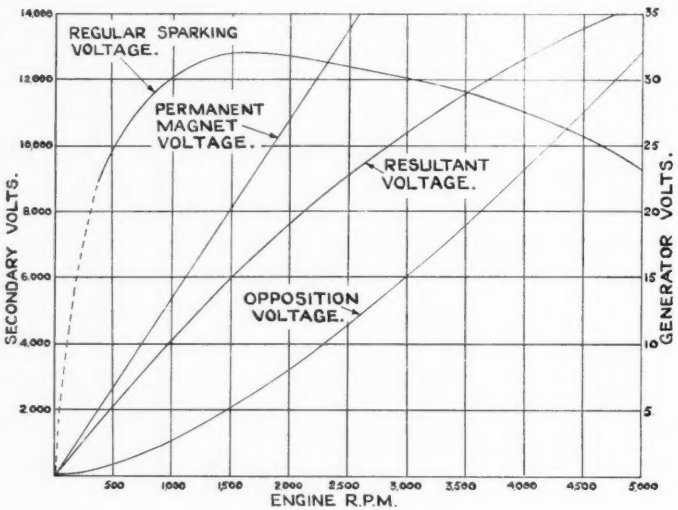

FIG. 27 COIL IGNITION SYSTEM WITH MOCK-UP R.A.E. SELF REGULATING GENERATOR.

NO BATTERY.	SECONDARY SHUNTED CAPACITY 200M.M.FDS
ANGLE OF CLOSED CIRCUIT	= 15°
ANGLE OF OPEN CIRCUIT	= 15°
TOTAL PRIMARY RESISTANCE	= 1·9 OHMS
PRIMARY CONDENSER	= 0·4 M.F.D

(*b*) SELF-REGULATING GENERATOR.

Two recent developments have enabled solutions to be obtained to these difficulties. The first is the design of a generator by Debenham (12), the voltage of which varies with speed at less than a linear rate, without using a voltage regulator. The generator is a combination of the permanent magnet and the shunt wound types, the shunt winding being arranged so as to set up a voltage in opposition to that induced by the magnet. This is depicted in Fig. 26. The shunt winding and its laminated core are spaced along the armature from the permanent magnet and the poles arranged so as to be in opposition to those of the permanent magnet; the opposing voltage increasing with increase of both armature voltage and speed. Fig. 27 shows the two components of the voltage and the resultant voltage of the generator. With a generator of this type, which weighs approximately 10lb., we are able to get a speed range of about 12:1. As will be seen from the performance curves given in Fig. 25, the lower limits and the upper limits of speed for a load of 200 m.m.fds. and 200,000 ohms are 40 and 500 sparks respectively.

An ignition system working on this scheme is shown diagrammatically in Fig. 28. It would comprise two self-regulating generators with starting apparatus. Only one L.T. lead per set of plugs is required with the usual L.T. switch. No ignition interference during starting or idling would occur if a completely screened starter magneto is used, but there would be prohibitive interference during starting if a buzzer coil supplied by the aircraft battery is used.

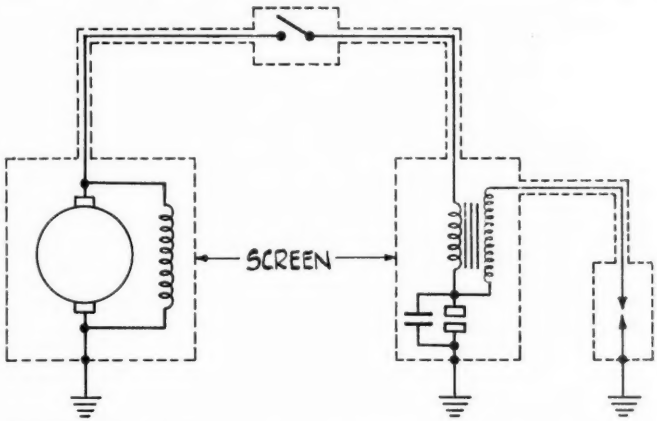

FIG. 28. DIAGRAM OF CONNECTIONS OF COIL IGNITION SYSTEM WITH SELF REGULATING GENERATOR (AUXILIARY APPARATUS REQUIRED FOR STARTING)

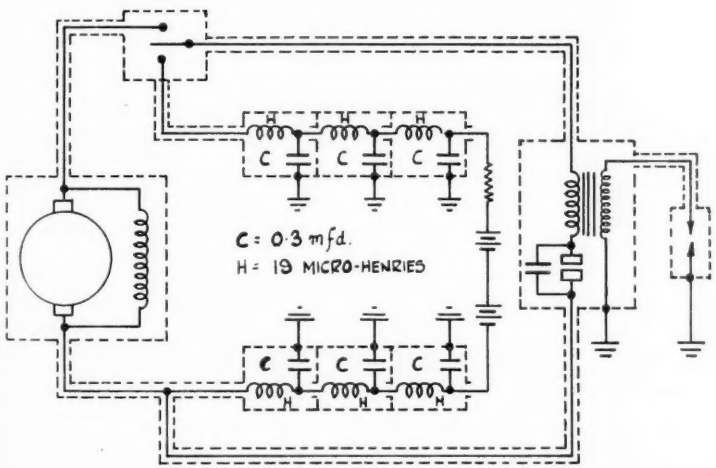

FIG. 29. DIAGRAM OF CONNECTIONS OF COIL IGNITION SYSTEM WITH SELF REGULATING GENERATOR, BATTERY STARTING, CHANGE-OVER SWITCH & INTERFERENCE SUPPRESSOR

(*c*) Interference Suppressors.

Alexander and Debenham (13) have shown that a three-stage choke-capacity suppressor device can be designed to suppress all interference over the service S.W. and V.S.W. bands. When this device is inserted in the primary of the coil, starting current can be obtained from the aircraft battery without any interference at any engine speed. Fig. 29 shows the scheme. One self-regulating generator and one single-pole switch is required per set of plugs, the whole system screened as shown.

4. Other Types of Ignition Systems.

The search for alternatives to the orthodox magneto has been actively taken up by the ignition apparatus manufacturers of this country during the past two years. The underlying idea is that if a different type of magneto discharge can be obtained which is of shorter duration than the ordinary magneto, then spark plug electrode erosion will be decreased, and also certain troubles at high altitude conditions such as the phenomena dealt with in paragraph *2d* and Fig. 23 will be more easily eliminated. It will be clear from later discussions that spark energy and length of tail of the discharge are not the primary factors in causing electrode erosion. The two most important factors are the magnitude of the combined capacity of the H.T. cables with that of the spark plug, and the amount of damping that can be applied to the spark itself. The problem to be solved, therefore, is to produce a spark discharge of *considerably* shorter duration than the ordinary magneto, but at the same time, the secondary circuit must not react in any greater degree than the magneto, when loaded with the capacity of the H.T. cables, and the equivalent shunt resistance of leaky plugs.

One of the earliest schemes was the Coats (14) ignition system invented about 35 years ago. It comprised an L.T. alternator giving a crest voltage of about 800 volts arranged to charge a condenser, which was discharged by a suitable contact maker through the primary of an induction coil, the secondary of the coil being connected to the spark plug. It was a very primitive device and had a very poor performance on load.

The application of an A.C. generator supply in association with a condenser discharge in the primary of a coil is being developed by several British ignition apparatus manufacturers, but it is too early yet to say what can be achieved by these means.

The General Motors Corporation (15) of U.S.A. have described in a series of patents the use of an alternator with a very peaky wave, driven at half engine speed, and having a number of poles equal to the number of cylinders. The discharge from a condenser is passed through a gaseous valve, of a type which suddenly breaks down when the voltage attains a predetermined value, into the primary of a transformer and the secondary produces the necessary spark. No contact breaker is used and the timing of the spark is supposed to synchronise with the peak of the alternator. Actually the timing is retarded increasingly as the speed is advanced. An automatic advance device is therefore provided to compensate for the retardation. No details are available of the capabilities of the scheme, but it appears complicated. It requires the following units, an alternator, an auto-transformer (to improve the timing of the spark), an automatic switch device, a discharge tube, a step-up transformer and the usual distributor.

5. Sparking Plugs.

The limit of possible development of mica insulated sparking plugs has very nearly been reached. The chief difficulties have been caused by the deposits from the lead content of the T.E.L. fuel. These deposits, although in some cases they have been known to cause pre-ignition, are not particularly deleterious until the surface temperature reaches about 600°C., when they fuse on to the mica, causing a blistered surface of comparatively high electrical conductivity.

About twelve months ago a prolonged series of measurements were made over a period of six months on a large number of plugs on different engines in flight, mostly with 18 m.m. thread diameter, a number with 14 m.m. and a few with 12 m.m. thread diameter. The engines were air-cooled and water-cooled types, and the fuels used were to D.T.D. Specification 224, or T.E.L. to D.T.D. 230 (octane number 87). The insulation resistance was measured by means of the R.A.E. high voltage leak resistance tester giving a peak voltage of 7,000 to 8,000 volts; 624 tests were made altogether and the Table III is an analysis of the results.

TABLE III.

Fuel and type of engine.	% of plugs with a resistance of <5 megohms	<1.0 megohms	<0.5 megohms	<0.2 megohms
D.T.D. 224				
A/C engines ...	10.3	5.2	4.2	3.3
W/C ,, ...	11.7	3.1	1.6	1.6
All ,, ...	10.8	4.4	3.2	2.6
D.T.D. 230 (T.E.L.)				
A/C engines ...	23.6	15.6	12.6	5.0
W/C ,, ...	21.4	20.2	17.9	13.1
All ,, ...	23.0	17.0	14.1	7.4
Grand total ...	16.4	10.1	8.2	4.8

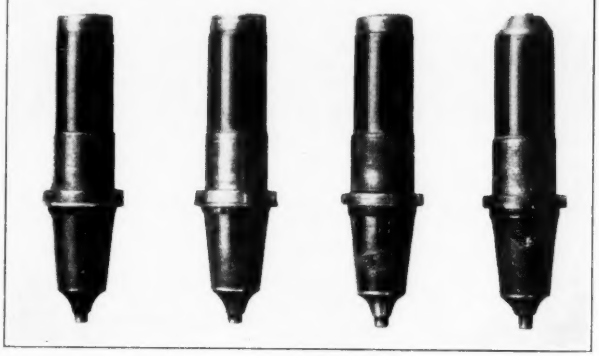

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FIG. 30.

Pinholing of insulators of mica-insulated sparking plugs.

The big increase in electrical leakage when using T.E.L. fuel compared with D.T.D. 224 is very noticeable and especially of plugs having resistance at the lower figures of between 0.5 to 0.2 megohm.

Another effect of lead attack has been very troublesome—that of partial disintegration of the mica by pinholes punctured right through to the central electrode. Fig. 30 shows the appearance of the mica surface in a number of typical cases, the first two showing the characteristic " pin-hole " and the other two showing others in a more advanced stage of disintegration. These faulty plugs were characterised by the following features (see Fig. 31):—

(*a*) Cavities or air spaces existed between the mica wrappings and surrounding mica washers. These cavities coincided with the punctures.

(*b*) Conducting deposits, chiefly compounds of lead arising from the use of T.E.L. fuel inside the mica insulation.

(*c*) Accumulation within the plug body of carbon or lead deposits so that the clearance between the mica insulation and the plug body is reduced.

(*d*) Wide plug gaps resulting in high spark voltage with consequent increase in electric stress on the air-cum-mica insulation between the plug body and the central electrode.

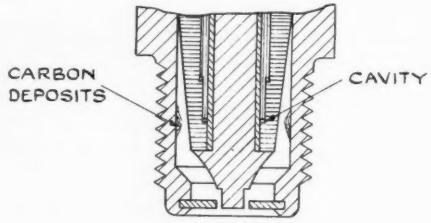

FIG. 31.

Diagrammatic representation of causes of pinholing.

The gradual deterioration in the electric strength of the path between the plug body and the central electrode in a radial direction caused by the presence of the lead deposits in the plug body, coupled with high spark voltages, ultimately caused preferential sparking between the plug body and the mica centre, rather than at the spark gap proper. This results in the punctures in the insulation. When once this phenomenon has started, disintegration is very rapid, the plug becomes very gas leaky, local overheating at the pinhole occurs and the original puncture is soon followed by local fusion of the mica of the kind seen in the last two plugs shown in Fig. 30.

In 1936 a new type of insulating material was developed in Germany by Messrs. Siemens which has provided a remedy for most of the troubles which have been experienced with mica plugs. It is aluminium oxide sintered to a very hard and impervious substance which is now manufactured in this country under the trade names of Corunite, Sintox, and Zircrund. It has twice the mechanical strength of best porcelain and five times better thermal conductivity. It is immune from lead attack by T.E.L. fuels. Its thermal expansion is nearer to that of nickel than that of ceramic materials, so that the sealing of the central electrode in the insulator is easier, because of the smaller difference in thermal expansion between the two. The cleaning of the insulation of such plugs is very easy, as even sand blasting does not spoil the insulating surface.

Intensive developments of plugs using this type of insulation have occurred during the past two years for experimental engines using fuels of both 87 and 100 octane value. On 87 octane fuel, periods of approximately 100 hours running have been obtained without any alteration to the plugs. Fig. 32 shows some typical designs which are giving very promising results. The difficulties which have still to be overcome and which can be attributed to the use of the aluminium oxide are chiefly concerned with designing a type of joint between the insulator and the body which is gas-tight without causing cracking. Cracking due to stresses set up under working conditions of change of temperatures have occurred at places where the section of the insulator changes. Copper and asbestos washers are not suitable in this respect and solid copper washers have caused distortion of the seating when locked up because of the large pressure required to effect a gas-tight joint. More success has been obtained with spring washers, but more development is still necessary. Trouble has also occurred through lead attack of the copper washer, causing excessive gas leakage.

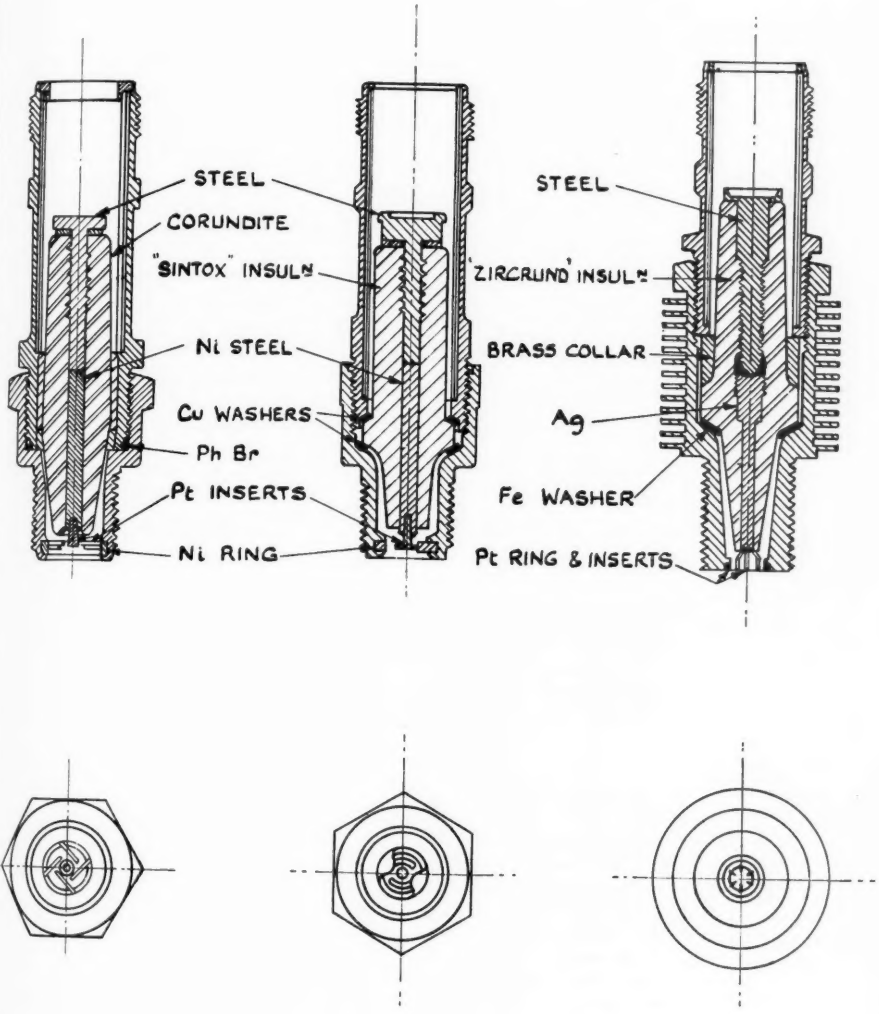

FIG. 32.

Typical sparking plugs with insulators made of sintered aluminium oxide.

Mis-firing due to low insulation resistance caused by carbon deposits has occurred; the operating temperature of the plug insulator being too low to burn off the deposits. Shortness of internal leakage path which facilitates flashover from the central electrode to the gland across deposits on the insulator has also been a limitation. The remedy is to provide a longer surface insulation without increasing too much the gas space inside the plug body.

6. Erosion of Sparking Plug Electrodes.

Erosion of the electrodes of sparking plugs is an important factor in limiting the development of engines using fuels of 87 and 100 octane value. The erosion has three effects, the frequent removal of sparking plugs to reset the gap, increase of spark voltage and therefore increase of voltage stress on the magneto, and reduction of the factor of safety of the whole ignition system at high altitudes due to the rise of the plug voltage.

It has been customary until a short time ago to remove plugs for re-setting the gap, after intervals of not more than 40 hours' engine running, but plugs now being developed show a big improvement. For example, some water-cooled engines on fuel of 87 octane value have completed tests of 100 hours' duration without attention.

Air-cooled engines, 7.3 compression ratio, giving an M.E.P. of 220 lb./sq. in. have on fuel of 100 octane value completed tests of more than 100 hours' duration without adjustment, an initial average setting of 0.015in. increasing to 0.020in. There is, however, considerable investigation required before we can reach the ideal of 400 hours' intervals between replacement.

(*a*) Effect of Electrode Material.

The erosion of electrode materials has been dealt with very fully in a report by Debenham and Haydon (16) published three years ago, a large number of metals, including ferrous alloys, nickel chromium alloys, tungsten, stellite, and various alloys of very high nickel content were tested in engines using 87 octane fuel. It was found that tungsten erodes least, pure nickel was second in order of merit, about 20 per cent. greater, followed by the nickel alloys. A number of the ferrous alloys showed double the erosion given by pure nickel. Tungsten, however, has an abnormally high spark voltage. It is also unsuitable because of the difficulty of working it, and its brittleness makes adjustment of the gap practically impossible.

Subsequent work on the precious group of metals has given very interesting results. Platinum electrodes show an erosion approximately one-quarter that of nickel; iridium about one-fifth that of nickel. Several nickel-rhodium alloys have been tested but with inferior results to pure nickel. Platinum is found to be somewhat soft and difficulty has been experienced in securing the electrode tightly into the body of the plug. Iridium is much harder and has more rigidity for this purpose. The best results are now being obtained with a Pt-Ir alloy containing 20 per cent. Ir. Two phenomena of interest which have occurred with the Pt-Ir alloy are shown in Fig. 33. The first is the development of transverse fissures at the junction of the central electrode wire with the nickel electrode shown by the arrow in the same figure at A. When the fissures are fully developed the wire falls off. It is well known that when platinum and certain platinum alloys are heated in a carbonaceous atmosphere, intergranular separation of the metal occurs. This action appears to be accelerated if stresses are imposed on metal simultaneously. In the case of the electrode depicted, stresses due to a cantilever construction and vibration would occur and cause stress-corrosion failure at the root of the wire. The other effect is the formation of globular shaped masses on the end of the electrode. The cause of these globular masses is not definitely known, but is possibly due to fusion resulting from sparking.

Molybdenum shows only half the erosion of nickel, but is abnormal in that the surface of the central electrode is chemically corroded by the T.E.L. fuel, an effect which has not been observed on any of the other materials that have been tested.

(*b*) Effect of Variation of Initial Plug Gap Size.

Twelve Lodge A.2-2 sparking plugs in which two of the three electrodes were cut away so as to increase the rate of erosion and make the measurements more accurate. Three lots of four each were set at 0.012in., 0.018in. and 0.024in. respectively. The plugs were tested in a Kestrel X engine, run at 9/10th full power at 2,350 r.p.m. with T.E.L. fuel. The magneto was a B.T.H. S.C. 12 magneto connected to the plugs with six feet lengths of screened cable.

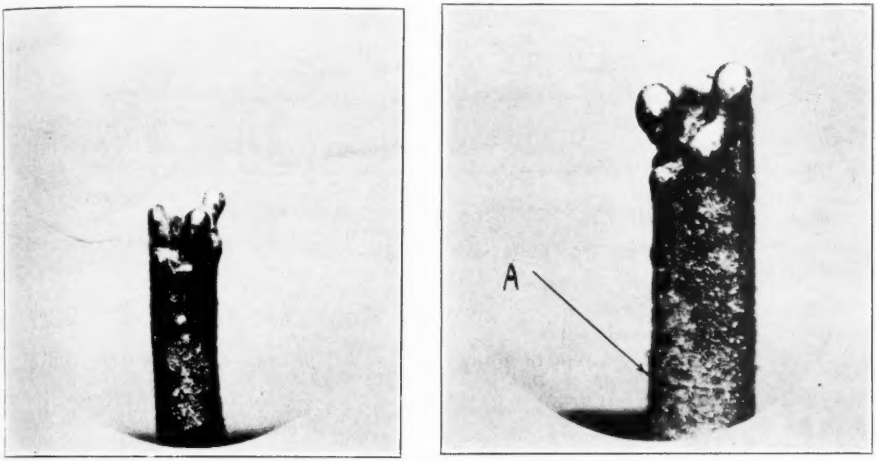

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FIG. 33.

Showing globular formations and transverse fissure on Pt-Ir electrodes.

The average erosion at the end of 10 and 20 hours was as follows:—

Initial gap.	At the end of 10 hrs.	At the end of 20 hrs.
In.	In.	In.
0.012	0.007	0.0135
0.018	0.0075	0.0115
0.024	0.0048	0.0095

It will be noted that the rate of erosion shows little difference in results whether the gap is 0.012 or 0.018in. and that with a gap 0.024in. the rate of increase of gap actually decreases.

Increase of voltage does not therefore increase the rate of increase of gap, but it is probable that in the very large gap the erosion of material was spread over a larger area caused by greater wandering of the spark.

(*c*) Effect of Capacity of Cables and Nature of Spark Discharge.

Electrode erosion is increased by increase of the electrical capacity of the cables which results when a complete screen is added to the H.T. system for the purpose of eliminating ignition interference to radio reception. Such

screening, whether by braided cables, or running the cables in metal conduits, adds a capacity of 100 to 200 micro-microfarads, depending upon the engine layout. Actual tests on a Kestrel X engine show that the erosion is increased by 2.6 times when screened cables 9 feet long are substituted for unscreened cables and the erosion is approximately proportional to the length of the cable. The results are shown in Fig. 34.

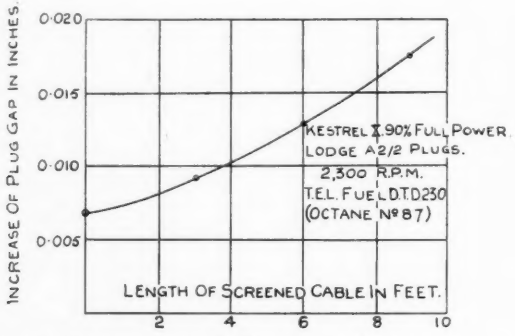


FIG. 34. VARIATION OF EROSION OF SPARKING PLUG ELECTRODES WITH LENGTH OF SCREENED CABLES.

Broadly speaking, there are two directions in which a reduction of this electrode erosion can be effected:—

(*a*) By developing a type of ignition system which has a much shorter "tail" to the spark discharge.

(*b*) By adding damping in the circuit so that the destructive effects of the current in the spark discharge are reduced.

As regards the first method it has, for example, been suggested that present-day magnetos give too large a spark energy, and that if this energy could be reduced, this should reduce the electrode erosion. Unfortunately there is not a direct correlation between the two effects. The following Table IV gives the results of some tests made under laboratory conditions using three different types of magnetos, two of which were purposely weakened so as to reduce the spark energy.

TABLE IV.

	B.T.H. S.C.9	Rotax S.P.12	Scintilla 9 cylinder.	B.T.H.S.C.9 magnets weakened	Rotax S.P.12 magnets weakened
Increase in electrode gap in thous. of inch. Unscreened cables ...	5·5	5	4·3	4·5	4·7
Ditto. Screened cables 6ft. long	13·0	15	14	15	21
Spark energy in Joules spark at 2,000 r.p.m.	0.041	0.041	0.029	0.022	0.012

It will be seen that with unscreened cables there is not very much variation in erosion over a variation of energy between 0.012 to 0.041, and that with screened cables the erosion is much greater with the least powerful magneto. There is therefore no direct correlation between spark energy and erosion.

The magneto impulse may be modified in several ways so that the " tail " of the discharge is cut. For example, by using a series condenser in the last layer of the secondary windings as is done in the Bosch Z.M. 12 magneto or by some of the alternatives to magnetos dealt with in the earlier part of this paper.

Useful as these methods of modifying the nature of the discharge are in reducing the erosion somewhat, it would appear that we must look elsewhere if we are to attain any big reduction in the erosion. We have already seen from the oscillographs shown in the earlier part of the paper that the spark discharge is of a very complicated nature and that after the initial spark which fires the explosion mixture, there is a succession of other discharges which vary with the plug capacity, capacity of cables, shunt resistance, etc.

Calorimetric tests have shown that the total energy expended on the spark is only slightly reduced by the addition of capacity, but the number of sparks in the total discharge decreases. Now the total energy in a capacity C charged to voltage $V = \frac{1}{2} CV^2$ and we can to a first approximation write

$$(n/2)\, CV^2 = J = \text{total energy in the spark,}$$

where n = number of separate discharges in the spark.

Therefore the number of sparks in the train (assuming it to be in such condition that it does not degenerate into an arc, which is the case in an engine) should be inversely proportional to the capacity. This has been confirmed experimentally.

This relationship is useful in considering what features of the discharge are responsible for the erosion. The most natural assumption to make is that erosion is related to the total quantity of electricity which passes through the gap. Assume therefore that

$$\text{Erosion} = E = k \,.\, n \,.\, Q$$

where Q = quantity of electricity passed in each discharge and k = a constant.

$$\therefore\ E = knCV = 2\, kJ/V.$$

Erosion should therefore be proportional to the total energy and should be inversely proportional to the voltage of the spark, neither of which deductions is in accordance with experiment. Erosion is therefore not directly related to the quantity in the discharge.

Finch and Mole (17) have suggested that the erosion is controlled mainly by cathodic spluttering, *i.e.*, the disintegration of the cathode by bombardment of positive ions. Erosion should therefore be increased considerably by an increase in the average voltage of the discharge which we have seen is not confirmed by experiment. Moreover, Debenham and Haydon (16) have shown that in a spark plug in which both the H.T. and earth electrodes are composed of the same material, the erosion for both cathode and anode are of the same order of magnitude. The increased erosion from the anode must obviously be associated with that part of the discharge carried by + metallic ions. Since the rate of formation of such ions is affected by a number of variables which vary very considerably in different engines and different designs of sparking plugs, such as—

(*a*) The turbulence of the explosive mixture at the moment of firing,
(*b*) The swirl of the flaming gas passing the electrodes after the explosion,
(*c*) The temperature of the electrodes,
(*d*) The amount of protrusion of the electrodes,
(*e*) The amount of screening available at the point where the sparks occur,

it is clear that we are faced by very complicated phenomena, of which little is known. Then in addition to the complex electrical effects which occur there is no doubt considerable actual vaporisation of electrode metal.

There are, however, two important facts to be noted. First, the amount of secondary capacity is directly related to the amount of the erosion and the peak current itself is very large. Fleming (18) has collected the results of a number of observations on effective spark resistance from which it appears that for spark gaps in air, and values of capacities of the order that we have to deal with, the

spark resistance varies from 3 to 16 ohms. It is clear that the peak current in the spark current is of the order of some hundreds of amperes. When subjected to a vigorous air blast this current would be reduced considerably, but it would still be high. Gill and Whitehead (19) quote a figure of 30 amperes as having been obtained on a motor car engine.

We must therefore find a solution to the erosion problem which does two things, reduce the effect of the capacity to a minimum and increase the damping effect in the spark, so that the spark current is reduced. Reduction of capacity to much below 150-200 micro-microfarads is impracticable except by the use of a very bulky H.T. cable system. This remains a fundamental difficulty which no amount of ingenuity in the design of ignition systems alternative to magnetos or orthodox coil systems can surmount except to a limited extent.

(*d*) Effect of the Distributed Nature of the Capacity.

Let us consider a typical H.T. cable enclosed in its braided sheath or a conduit as the case may be (Fig. 35). When the contact breaker opens there is created in the secondary a transient damped oscillation of electromotive force, determined by the various electrical constants of the primary and secondary of the magneto and the total capacity of the cable. The frequency of the oscillation is of the order of 10,000 cycles per second. During the rise of the E.M.F., the whole of the cable $a\ b$ and the sparking plug follow the potential of the point M perfectly in phase because the reactance of $a\ b$ is negligible. As soon as the spark occurs at the sparking plug, an oscillation occurs in the cable of very high frequency, of the order of 10^7 to 10^8 cycles per second. This oscillation is determined by the inductance and capacity of the cable and spark plug, but not as a simple parallel circuit composed of the total inductance and total capacity of the cable, but as a "distributed" circuit depicted in Fig. 35*b*. The effect on the current flowing through the spark from the discharging cable depends upon the distance from the spark of the portion of the cable which is discharging. Thus the element C'_1 discharges instantaneously into the spark since there is no inductance to impede the flow; the discharge of element C_2 is hindered by the element of inductance l_1: that of C_3 by l_1 and l_2, and so on. Actually, of course, the subdivision of the inductance and capacity of the cable is uniform throughout the cable, *i.e.*, the subdivision into elements in the figure must be imagined as carried out to an infinite extent.

The theoretical investigation of this system of distributed capacity and inductance shows that there is an infinite series of oscillation frequencies, the principal one being equal to

$$n = 1/4\sqrt{LC}$$

where C = total capacity of cable,
L = total inductance of cable,

together with all the higher odd harmonics $3n$, $5n$, $7n$. It can be shown that if the spark is regarded as of negligible resistance, then the R.M.S. current flowing at any point distance x away from the spark is proportional to

$$\{ (4/\pi)\sqrt{(C/L)} \}\ \sqrt{\ \{ \cos^2 (\pi x/2l) + (1/9)\cos^2 (3\pi x/2l) + (1/25)\cos^2 (5\pi x/2l) + \ldots \}}$$

where l = total length of cable.

The quantity defined by the second square root is shown in the curve of Fig. 36.

Some actual measurements of the current in a braided cable feeding a spark are given in Fig. 37, Curve A. They were obtained by making small breaks in the braiding and core at selected places and inserting a small vacuo type of thermal junction in the core. The general form of the curve is similar to the theoretical one, except that at the magneto end of the cable, there is a small amount of current which must obviously be contributed by the oscillations in the capacities on the magneto side of the cable, such as the distributor and part of

the secondary winding caused by the distributor spark gap, and also by the low frequency alternator e.m.f. of the magneto.

(*e*) THE USE OF SERIES RESISTANCE.

It will now be apparent that the problem of reduction of electrode erosion can only be effectively solved by inserting as much damping in the spark as possible,

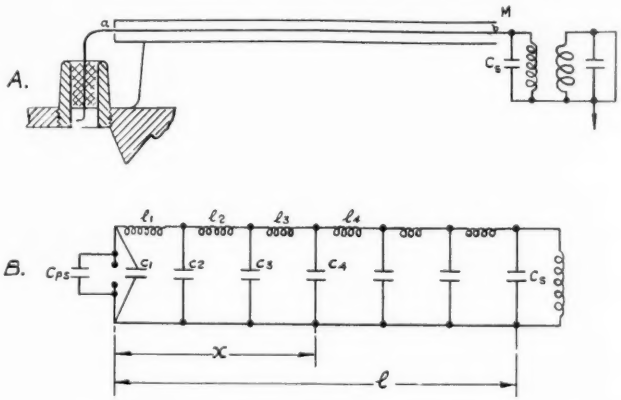


FIG 35 DIAGRAMMATIC REPRESENTATION OF DISTRIBUTED CAPACITY INDUCTANCE OF H.T. CABLE SYSTEM.

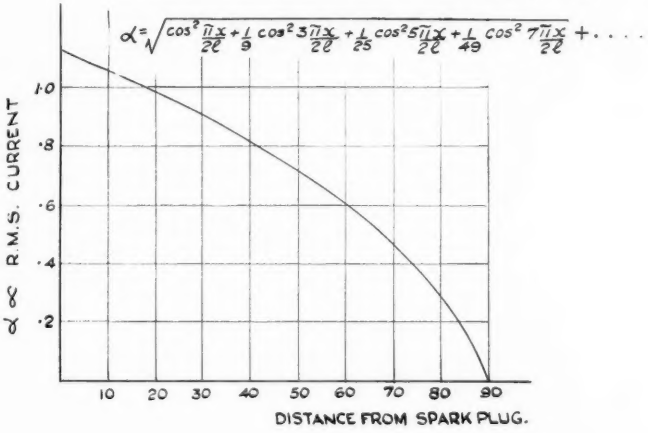


FIG 36 SHOWING VARIATION OF R.M.S. CURRENT CALCULATED IN THE CONDUCTORS WITH DISTANCE FROM SPARK.

and that the effectiveness of the remedy is the greater, the nearer that it is applied to the actual spark. The addition of series resistance in the cables has been the subject of considerable experiment at the engine constructors works and at the R.A.E. The results of tests on the effect of such an insertion are given in Fig. 37. Curve B shows how 960 ohms at the magneto end affected the current

at various points in the cable, whilst Curve C shows its effect at the sparking plug end. In the latter case the current at the plug end drops from 170 m.a. to 16 m.a.

The effect on the electrode erosion has been determined for various amounts of resistance and the results are shown in Fig. 38. It will be seen that :—

(*a*) The erosion is reduced by about 70 per cent. when a resistance of 1,000 to 2,000 ohms is inserted at the plug end;

(*b*) The addition of further resistance up to 50,000 ohms does not effect much more improvement;

(*c*) With resistances greater than about 2,000 ohms, the erosion with 6 feet of braided cables is only a little more than the erosion with unscreened cables and resistance;

(*d*) The effect of inserting 10,000 ohms at the magneto end is negligible.

A form of attachment to the screen of sparking plugs designed by Messrs. K.L.G. is shown in Fig. 39, the resistor being held in position between the cable end fitting and the central electrode by a spring. By its use the life of present-day standard plugs between maintenance operation is increased by about three times, and would allow such plugs to be run for 80-100 hours without adjustment of the gaps.

(*f*) Comparative Tests of Erosion with Magnetos and Coil Systems.

Some comparative tests have been made on a Kestrel X engine of the relative erosion with magneto and coil systems. T.E.L. fuel to D.T.D. 230, the engine running at 9/10 full power and 2,350 r.p.m.

In order to get the most accurate measurements, Lodge A 2-2 plugs were used and two of the three earth electrodes cut off. Tests were made with a generator-operated coil and a battery-operated coil, using unscreened cables and screened cables. Tests were also made on the latter condition with 1,000 ohm resistors. The results are given in Table V, the values being the average for four plugs. At intervals of ten hours the plug positions were changed so that for any plug the time of running in an inlet or exhaust position, in A block or B block and with + or − polarity, was equal after the total duration of 40 hours.

Table V.

Erosion Tests on Kestrel X.

(Values in thousandths of an inch.)

Initial gap 0.012in.

	Test 1				Test 2			
	Magneto		Coil Generator-operated		Magneto		Coil Battery-operated	
H.T. lead	20 hrs.	40 hrs.	20 hrs.	40 hrs.	20 hrs.	40 hrs.	20 hrs.	40 hrs.
6ft. unscreened cable ...	7.0	12.5	6.5	12.5	—	—	8.5	15.5
6ft. screened cable ...	13.5	22.5	9.5	17.5	13.5	21.5	10.0	17.3
6ft. screened cable and 1,000 ohms	3.5	7.0	4.5	8.5	—	—	4.0	8.0

It will be seen that there is very little difference in the erosion obtained by either type of ignition system.

(*g*) Effect of Electrode Shape and Material on Erosion.

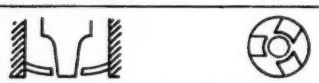
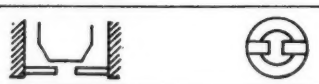
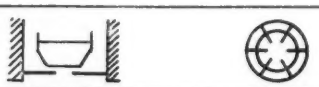
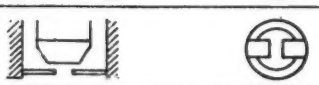
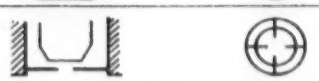
Table VI gives the results of a number of tests which have been made over a period of years in different engines in flight with different designs of electrodes and different materials and taking them in order from top to bottom give a rough idea of the progress made during the past three or four years.

Table VI.

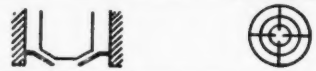
Average Rates of Plug Electrode Erosion

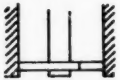
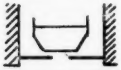
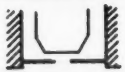
TABLE VI.

AVERAGE RATES OF PLUG ELECTRODE EROSION DURING FLIGHT TESTS OF 20-30 HOURS DURATION ON FUEL TO SPECIFICATION D.T.D. 230.

No.	ELECTRODES	MATERIAL OF ELECTRODES		ENGINE	AVERAGE EROSION INCH/HOUR	REMARKS
		CENTRAL	EARTH			
1		STEEL	NICKEL	JUPITER VIII F	0".0007	
2		NICKEL STEEL	NICKEL	MERLIN I	0".0005	
3		NICKEL STEEL	NICKEL	KESTREL X	0·0005	*
4		NICKEL STEEL	NICKEL	KESTREL V	0·0004	
5		NICKEL STEEL	PLATINUM-IRIDIUM WIRE.	CYCLONE	0·00033	
6		NICKEL STEEL	NICKEL STEEL	KESTREL X	0·00035	*
7		MANGO-NICKEL	NICKEL	CYCLONE	0·00033	
8		NICKEL	NICKEL	KESTREL V	0·00032	
		"	"	KESTREL X	0·00023	
9		NICKEL STEEL	PLATINUM-IRIDIUM WIRE	MERCURY IX	0·00028	
10		NICKEL STEEL	NICKEL	PEGASUS III	0·00022	Spark somewhat baffled
11		NICKEL STEEL	NICKEL	MERLIN II	0·0002	
		NICKEL STEEL	NICKEL	PEGASUS III	0·00018	
12		PLATINUM	PLATINUM	RAPIER VI	0·00015-0·00020	
13		"	"	MERLIN II	0·00015	
14		NICKEL STEEL	STEEL	CHEETAH IX	0·00015	Not suitable for modern high duty engines
15		NICKEL STEEL	PLATINUM-IRIDIUM WIRE	MERLIN II	0·00015	
16		PLATINUM IRIDIUM	PLATINUM-IRIDIUM WIRE	MERLIN II	0·00015	
17		NICKEL	NICKEL	PEGASUS XX	0·0001	*

* Bench test.

4		NICKEL STEEL	NICKEL	KESTREL V	0·0004	
5		NICKEL STEEL	PLATINUM-IRIDIUM WIRE.	CYCLONE	0·00033	
6		NICKEL STEEL	NICKEL STEEL	KESTREL X	0·00035	*
7		MANGO-NICKEL	NICKEL	CYCLONE	0·00033	
8		NICKEL	NICKEL	KESTREL V	0·00032	

8			NICKEL	NICKEL	KESTREL V	0·00032	
			"	"	KESTREL X	0·00023	
9			NICKEL STEEL	PLATINUM-IRIDIUM WIRE	MERCURY IX	0·00028	
10			NICKEL STEEL	NICKEL	PEGASUS III	0·00022	Spark somewhat baffled
11			NICKEL STEEL	NICKEL	MERLIN II	0·0002	
			NICKEL STEEL	NICKEL	PEGASUS III	0·00018	
12			PLATINUM	PLATINUM	RAPIER VI	0·00015-0·00020	
13			"	"	MERLIN II	0·00015	
14			NICKEL STEEL	STEEL	CHEETAH IX	0·00015	Not suitable for modern high duty engines
15			NICKEL STEEL	PLATINUM-IRIDIUM WIRE	MERLIN II	0·00015	
16			PLATINUM IRIDIUM	PLATINUM-IRIDIUM WIRE	MERLIN II	0·00015	
17			NICKEL	NICKEL	PEGASUS XX	0·0001	*

* Bench test.

The combination of the best of these, for example, 12, 15, 16 and 17, with resistors has not yet been tested, but there would appear to be good promise of thereby raising the period between readjustment of the gaps to approximately 200 hours.

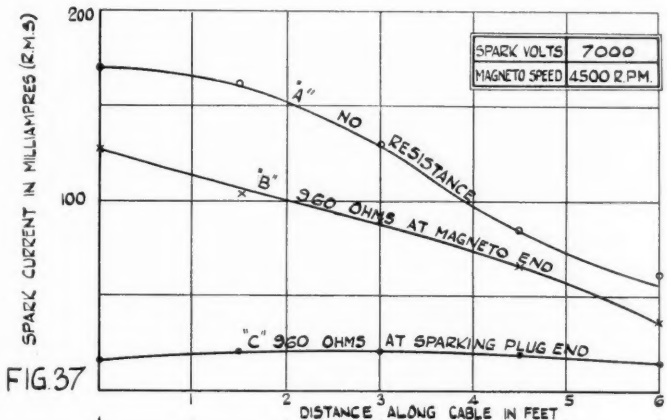


FIG. 37

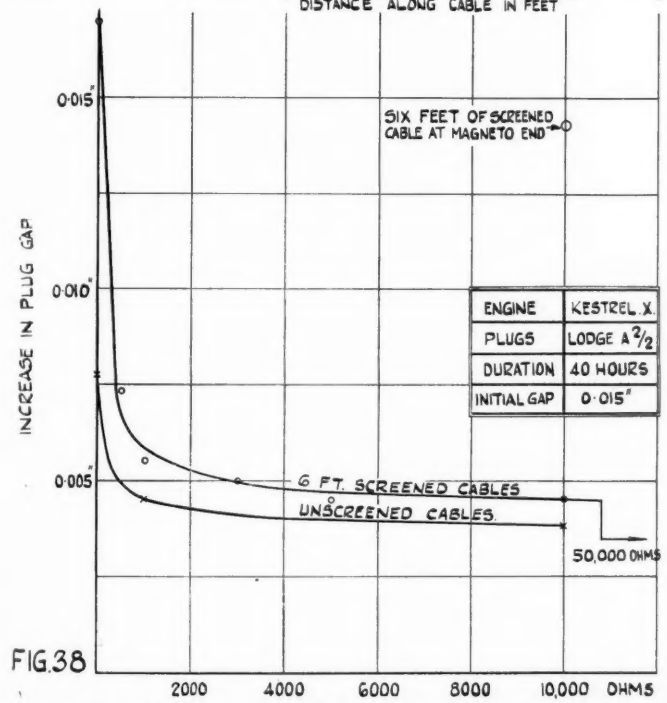


FIG. 38

FIG. 37. SHEWING EFFECT OF SERIES RESISTANCE ON SPARK CURRENT (R.M.S.)

FIG. 38. SHEWING THE EFFECT OF INSERTION OF SERIES RESISTANCE AT THE SPARK PLUG ON THE EROSION OF SPARKING PLUG ELECTRODES.

7. Bonding and Screening.

Every spark discharge in the ignition system, whether at the sparking plug, the distributor rotor gap, or the contact breaker, causes electro-magnetic radiation to be radiated from the spark and the associated circuits. This, on aircraft with the usual types of short-wave receivers, causes such an intense background of noise as to prevent completely reception being obtained anywhere over a very wide band of wave lengths. To eliminate this background of noise it is necessary to enclose the whole of the ignition system, *i.e.*, primary and secondary circuits, in a complete metallic screen. In addition, it is necessary for the parts of the screen which surround the cables to be bonded to the engine, or to the aeroplane structure in the case of the L.T. wiring, at points not more than 18 inches apart, and where radio reception is required on wave lengths as low as one to two metres such bonding is preferably done at more frequent intervals, *i.e.*, not more than about 6 to 9 inches apart.

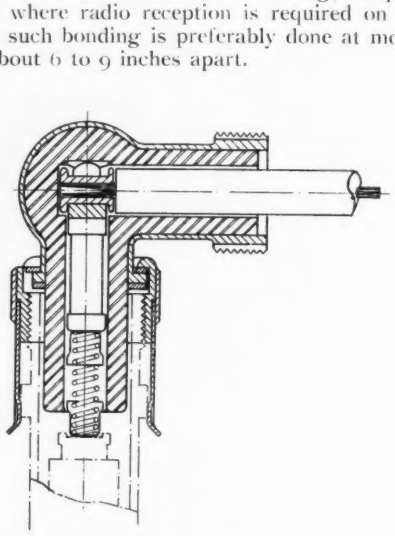


Fig. 39.

Resistance unit in screening elbow. K.L.G. B.R. 90/1.

The screens in conjunction with the structure of the ignition apparatus have to be continuous without aperture or gaps except in so far as required for ventilation. Machined faces must be of adequate bearing area and fitted so that sound and reliable metal to metal joints of low electrical resistance are obtained. Ventilation must be provided by one or more holes $\frac{1}{16}$in. diameter, not too close together, in each screen. Alternatively, small apertures each not exceeding 0.15in. sq. in. area covered with two layers of 70-80 mesh copper or brass gauze, or other equivalent type of flame trap, may be used.

Joints between magnetos, screens, cables and sparking plug fittings must be of a rigid nature; non-metallic jointing materials are a fruitful source of radio interference and are therefore prohibited.

In modern practice the H.T. cables are run either (1) in separate braided cables, or (2) in a manifold in which there are outlets to which flexible braided tubes are attached with ferrules and screwed nuts to connect the manifold to the sparking plugs. The cables are then threaded through the manifold into the flexible tubes. The manifolds are securely fixed and bonded to the engines and the flexible tubes are provided for the removal of the sparking plugs. The sparking plugs also are provided with shields of the types depicted in Fig. 39.

Braided cables have been the subject of much development to obtain reliability under conditions which are very exacting. They must have the following characteristics:—

(*a*) Resistance to oil;
(*b*) Resistance to petrol;
(*c*) Resistance to entry of water;
(*d*) Protection against deterioration by ozone produced by the H.T. electric stress;
(*e*) Ability to withstand considerable abrasion due to rough handling, vibration and wear.

They are capable of meeting conditions (*a*), (*b*), (*c*) and (*d*), but are not sufficiently robust to withstand rough handling. They are also difficult to maintain at a reasonably high standard of reliability because of the numerous bonding points at which they are attached to the engine. The modern tendency is to go over entirely to the manifold or harness scheme. This scheme, although heavier than braided cables, does enable a more robust flexible tube to be provided at the plug ends and the greater part of the cables can be housed out of danger in the manifold. The whole assembly is much neater.

The harness should be so arranged on the engine that fitting or removal of the complete unit or any of its component parts can be effected without removing the engine from the air-frame, and it must be possible to replace any H.T. cable with the harness *in situ*. The joints in the harness must therefore be arranged in accessible positions. The flexible conduits are usually made with an inner flexible metallic tube of high electrical conductivity and of interlock section. The outside of the tube is covered with a closely woven and tightly fitting braid of tinned copper or phosphor bronze wire. An outer braid of armouring made of phosphor bronze strip is used to protect it from mechanical injury. Ordinary flexible metallic tube, as used on speedometer drives, is quite useless, the variable nature of the electrical resistance between convolutions and the inductance of it being a source of interference to R/T equipment.

There are usually four vulnerable points on the harness:—

(*a*) Where the flexibles run near to the exhaust pipes;
(*b*) The parts of the flexibles which are bent most when they are detached from the sparking plugs;
(*c*) The last few inches of the flexible near the sparking plug;
(*d*) The connection between the cable and the sparking plug screen.

At (*a*) and (*c*) the effect of heat in the cables is in some engines very great. This point is dealt with later. As regards (*b*) considerably more development is required to obtain a flexible tube which will withstand the maximum amount of repeated flexure without breaking the braiding. As regards the sparking plug end connections, these cause considerable trouble due to the multiplicity of parts. Fretting and wear is frequent under engine vibration. This causes surface deposits of a conductive nature on the insulators in the connectors which have been troublesome.

8. Braided and Harness H.T. Cables for High Temperature Conditions.

(*a*) Effect of Heat.

The modern designs of high duty engines are imposing very difficult conditions, particularly as regards temperature on the H.T. cables. Some of the difficulties have arisen because of insufficient regard to the serious limitations of rubber or any flexible dielectric for withstanding heat, with the result that the layout of the cables in some cases has been designed with more regard to the rest of the engine than to providing reasonable conditions for the cables to function in. At the same time the rising of temperatures in modern aircraft installations with very close cowling have to be recognised and provided for as far as possible.

Temperatures as high as 140°C. have been measured when the engine is being run up on the ground and it is understood that new designs of cylinder heads where deep pockets for the sparking plugs are to be used, temperatures nearing 200°C. may occur. As rubber of the best quality used in H.T. cables can only last for a few hours at 130°C. before these are useless, it is clear that a very great increase in heat resisting properties is required before the new conditions can be met.

With metal braided screened cables the symptoms of trouble which are usually obtained are fine spewings of softened rubber forced through the varnished cambric tape which is wrapped round the rubber dielectric and through the wires of the braiding. On lacquered cotton braided cables which are used in harnesses, pimples are found on the lacquered surface, and in bad cases bulges appear in the cotton braiding due to internal pressure of the semi-fluid dielectric. In this condition withdrawal of faulty cable through the conduits is very difficult. The effect of heat on rubber varies considerably with different rubber mixes; some become soft and sticky at first and then gradually form a harder skin due to oxidation; whereas others do not soften to such an extent but harden more rapidly. All kinds in time lose their flexibility and fracture easily on removing them.

The high rate of oxidation of rubber at elevated temperature is a most serious limitation to the use of rubber. If it could be kept free from oxygen attack it could probably be made to give effective service up to 130°C. approximately. Attempts have been made and are still in progress to provide an oxygen impervious sheath. Coverings of cellulose lacquer either direct on the rubber or over a cotton braiding have given a certain measure of success. A more satisfactory method of construction consists of a lacquered coating over the rubber, followed by one or two layers of cotton braiding finished with a special (Sterling) oil varnish.

(*b*) Effect of Oil.

Lubricating oil has a serious effect on rubber cables, the oil being absorbed with consequent swelling. The forces set up by the swelling are quite sufficient to burst open the metal braiding of a braided cable if this has been damaged by chafing. Normally the varnished cambric tapes under the metal braiding prevent the oil reaching the rubber. The cellulose lacquer on the cotton braided cables, which have been standardised for use in conduits and harness, is very good protection against oil.

(*c*) Effect of Petrol.

Petrol has the same effect on rubber as lubricating oil, but to a much more serious degree. Fortunately petrol is not normally present on cables to the same extent as oil.

(*d*) Effect of Ozone.

Ozone has an exceedingly rapid oxidising effect on rubber, and the effect is greatly increased if the rubber is mechanically stressed. Ozone is liable to be formed wherever air trapped between cable dielectric and fittings or screen is subjected to high electric stress. Transverse splitting of rubber has frequently been found where the metal braiding and varnished cambric have been removed and the cable stressed by bending. Ozone is produced in conduits of screening harness, hence the necessity to provide ventilation as well as protection to the rubber. Satisfactory cotton braided rubber cables covered with a well applied layer of certain lacquers offer sufficient protection against ozone, providing temperature is not in excess of about 130°C.

(*e*) Alternative Materials to Rubber.

Several synthetic materials have been discovered in the past few years which can be used in partial substitution for rubber. Three of these are of value for ignition cables.

Thiokol is a condensation product of chlorinated ethylenes in the presence of sodium polysulphide.

It has very good resistance to oil, petrol and ozone, and the heat resisting properties of some variations, one somewhat better than those of rubber, although excessive heat makes it split on bending.

Neoprene is an artificial rubber which is a polymerised produce of chloroprene (a derivative of mono-vinyl acetate treated with hydrochloric acid). It is very resistant to oil, and stands up fairly well to petrol.

Perbunan is a polymerised product of butadiene (a derivative of ethylene by catalytic action).

It has as good oil resisting properties as neoprene, but is very seriously affected by ozone. Its dielectric constant is unfortunately much higher than that of rubber, 15 as compared with 4.5, so that it is hardly practicable for use, making a complete cable. It has, however, the highest heat resisting properties of any of the available flexible materials of those so far tested, which are suitable for H.T. cables, and is therefore likely to form a good sheath to rubber if we desire to make the best possible use of the heat resisting properties of rubber when made immune from oxygen attack.

None of these materials has as good electrical strength when new, but they are probably more stable and retain their electric strength at a higher proportionate level during their life than rubber does.

Table VII gives in compact form data which have been obtained on cables made of various materials. The work is far from complete yet, but so far as it has gone it would appear :—

1. That a good quality rubber cable covered with a cotton braiding varnished with an oil varnish applied so as to make a good seal is capable of giving moderately good service at 150°C.
2. That a cable consisting of rubber covered with a thin perbunan sheath and an oil varnished ozone-resisting braid would probably give the best results of any combination of materials tested so far, and that a cable of this type should be capable of withstanding the total period of ground running hours which would be associated with a total flying duration of 400 hours.
3. Considerably more experimental work is required to obtain cables to withstand temperatures between 150°C.-200°C.

9. Moulded Insulation for Use at High Temperatures.

There is a growing tendency to use fittings containing moulded electrical insulating parts in positions where the temperature is excessively high, for example, in pockets where the connector to the plug screen and the flexible connection to a manifold may reach temperatures of the order of 150°C. It appears desirable to consider the properties of moulded insulation at such elevated temperatures.

Fig. 40 shows the variation of electrical strength of some typical compounds with temperature up to 140°C.

A is a good quality synthetic resin of the phenol formaldehyde type with wood flour filler.

B is a similar material specially manufactured for high quality electrical mouldings.

In each case samples were tested as received and the humps on the curves are explained by drying out at the higher temperatures.

TABLE VII.

PROPERTIES OF MATERIALS FOR USE IN H.T. CABLES

No.	Materials.	Effect of heat.	Swelling after 20 hours in Lubricating oil at 100°C.	Swelling after 20 hours in Petrol	Effect of ozone.	Electrical strength
1	Rubber	100°C. Very flexible after 430 hrs. 130°C. Will last several hrs. 150°C. Sticky with some mixes. Hardens after a few hours with others.	Poor 20%	V. poor 39%-56%	V. poor	V. good
2	Rubber + sterling oil varnished cotton braid.	100°C. Good. 150°C. Still flexible after 100 hrs.	V. good Nil	Good 5%	Good	Good
3	Thiokol.	Fair.	V. good	V. good	V. good	Good
4	Thiokol + varnished cotton braiding.	110°C. Good. 150°C. 16 hrs. lacquer cracks on bending, pimples on braiding. 150°C. 24 hrs. braiding splits on bending. 150°C. 39 hrs. thiokol splits on braiding.	V. good Nil	V. good Nil	V. good	Good
5	Neoprene.	Somewhat better than rubber.	Good	Fair	Variable Fair to poor.	Good
6	Rubber + neoprene sheath.	100°C. Good. 150°C. Fairly flexible after 48 hrs. Some cracking on bending. 160°C. Hardens and cracks on bending, rubber melts.	Good Nil to 2.9%	Poor 36%-42%	Fair to poor Variable	Good
7	Perbunan	Better than rubber.	Good	Poor	V. poor	Approx. half that of rubber
8	Rubber + perbunan sheath.	100°C. Good. 150°C. After 100 hrs. reasonably flexible.	Good 2.2 to 2.9%	Poor 29%-34%	V. poor	Good
9	Thin layer of ozone resisting rubber + V.I.R. + thin layer of synthetic rubber + black well-adhering, lacquered cotton braid. (Callenders).	100°C. Good. 150°C. 16 hrs. fair 150°C. 48 hrs. hardened.	V. good 0.4%	Good 6.9%	Good	Good
10	Rubber + perbunan sheath + oil varnished braid.	No data available yet. Should be as good as No. 8.	Should be V. good	Should be as good as No. 8	Should be considerably better than No. 8	Good

C is a phenol formaldehyde synthetic resin with small flaked fabric filler.
D is a phenol formaldehyde synthetic resin, with heavy mineral loading.
E is similar to D.
F is a phenol formaldehyde synthetic resin with wood filler, but the impregnation of the wood flour by the resin is carried to a much greater degree than in A and B.

It is too early yet to say what depreciation in electric strength occurs with prolonged heating and also the influence of exposure to high humidity between periods of heating.

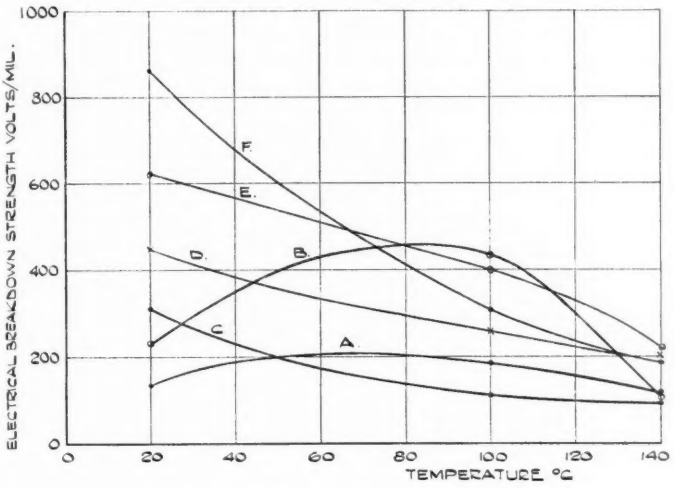


FIG. 40.

Variation of electrical breakdown strength with temperature of typical moulded insulating materials.

The limits of temperature for these materials when regarded from the mechanical resistance point of view are as follows:—

Material	A	130°C.
,,	B	130°C.
,,	C	120°C.
,,	D	170°C.
,,	E	170°C.
,,	F	130°C.

CONCLUSIONS.

Recapitulating the points dealt with in the paper:—

First, the necessity to attain 400 to 500 hours' maintenance free period from the whole of the ignition system between major overhauls of the engine.

Second, the following are the chief outstanding problems in what is considered to be the approximate order of importance:—

(1) Reduction of erosion of spark plug electrodes. Limitation at present 100 hours. Reasonable hopes in near future of reaching 200 hours.

(2) The development of the most efficient design of armature coils to meet load conditions and high speed operation, on the basic performance of 7,500 volts at 30,000 ohms and 200 m.m.fds. and at 500 sparks per sec. The present limit is about 350 sparks per second.

(3) Parallel with this, the further development of the specialised coil system which has been referred to, and the associated self-regulating generator.
(4) The determination of what advantages can be derived from other alternatives such as the condenser discharge scheme.
(5) Further developments of plug design with aluminium oxide insulators to meet higher M.E.P.s.
(6) Improvement of sparking plug screening fittings and harness flexibles.
(7) Development of ignition cables to meet very high temperature conditions.
(8) Improvement of performance of ignition systems for very high altitudes.
(9) Improvements of magnetos and ignition distributor units to meet high temperature conditions, effects on windings and bearings.
(10) Study of moulded insulation under alternating conditions of high humidity and high temperatures.

In conclusion, I hope that I have been able to give some idea of the difficulties which are encountered in designing ignition equipment for use on aero engines and that the information provided will enable the relationship of the various parts of the ignition system and the conditions on the engine to be seen in clear perspective and also that the nature of the difficulties which have to be solved will be appreciated.

I have to express my thanks to the Director of Technical Development, Air Ministry, for permission to publish this paper, and also to the following members of my staff, Messrs. G. Connock, W. R. Debenham, S. F. Follett, G. Haydon, G. C. Jones, F. Wilkinson, and E. Youel, who have contributed such a large amount to it in obtaining the bulk of the experimental data which it contains.

References.

1. N. Campbell and C. C. Paterson. "The characteristics of the spark discharge and its effects in igniting explosive mixtures." Advisory Com. for Aeronautics. Report E.S.C., No. 23.
2. G. E. Bairsto. "The effect of shunted resistance, or plug leakage on the sparking performance of an electrical ignition system." Journ. I.E.E., 1920, p. 507.
3. T. H. Darnell. "The automotive induction coil."
4. E. T. Jones. "The induction coil."
5. F. B. Silsbee. "Mathematical theory of induced voltage in an H.T. magneto."
6. G. E. Bairsto. "The relation between the number of secondary turns on a magneto armature and the secondary voltage with shunted resistance." Advisory Committee for Aeronautics, E.S.C. Report No. 52, 1919.
7. E. A. Watson. "Magnetos for ignition purposes on internal combustion engines." Journ. Inst. Elect. Eng., Vol. 301, p. 445.
8. G. E. Bairsto. Brit. Patent 214,682.
9. Bosch. Z.M.12 magneto.
10. Peeke. "Dielectric phenomena in high voltage engineering." McGraw-Hill & Co.
11. H. E. West. British Patent No. 440,133.
12. W. R. Debenham. British Patent Applic. No. 31,599/37.
13. D. P. Alexander and W. R. Debenham. British Patent Application No. 18,044/38.
14. Coats. British Patent 3,258 and 26,527.
15. Gen. Motor Corp. British Patent 427,679, 458,592 and 492,484.
16. W. R. Debenham and G. Haydon. "On the erosion of sparking plug electrode materials and the variation of sparking plug voltage." Aeronautical Research Com. Report. R. and M. No. 1,744.
17. G. I. Finch and G. Mole. "The mechanism of electrical ignition." Proc. Inst. Auto. Eng., 1934-35, Vol. 29, p. 71.
18. J. A. Fleming. Wireless telegraphy. MacMillan, pp. 228-237.
19. A. J. Gill and S. Whitehead. "Electrical interference with radio reception." Journ. Inst. Elect. Eng., Vol. 83, 1938, pp. 345-386.

Discussion.

The President: He would like to point out, to all responsible for producing modern ignition apparatus, that the engine maker was asking for a very high standard, much higher than ever before, and he made a strong plea for encouragement by the engine makers of the very best designs and the selection of the very best materials. It was of no use insisting upon the continuance of a restricted

design which did not give room for the proper disposition of the necessary apparatus. Another important matter he emphasised was that quality of workmanship must be paid for.

Mr. F. R. Banks (*Fellow*): The troubles which had been attributed to the use of leaded fuel might suggest that it would be a good thing to de-rate engine power by 50 per cent. and to use unleaded fuel; then they could use normal sparking plugs and would be free from trouble! However, he thanked heaven for the advent of Sinterkorund; as the result of that, lead would not be blamed in the future for sparking plug troubles, he hoped. About five years ago he had seen in Germany the first Sinterkorund plugs which had run on leaded fuel, mainly in motor car engines, and it had occurred to him then that matters would be improved very considerably if the same material were used for the insulators of aircraft engine plugs. In a paper in 1937 he had forecast that that would happen; and now the plug manufacturers had provided a Sinterkorund plug for aircraft engines which would operate for 100, and probably 200, hours, without trouble.

In regard to the effect of lead upon the plug points, he said he did not think it increased the rate of gap erosion. But the high duty permitted by the higher octane fuels did increase it, and then the plug broke down, if the insulation became coated with lead deposit, and if that deposit ran too hot, when it then acted as an electrical conductor instead of an insulator.

The only electrode material he knew which suffered a relatively high degree of hot corrosion attack by leaded fuel was molybdenum. Ordinarily, one could check if hot corrosion of the electrode by lead occurred, because this would be apparent at the electrode tip, outside the gap area, and no corrosion or reduction of the electrode end was usually obvious. Molybdenum showed up badly in that respect, but none of the other materials appeared to be unduly affected.

Commenting on the author's reference to the possible difference in plug life resulting from the use of 100 octane fuel, he agreed that there would be some difference, of course; but there was about the same amount of lead in 100 octane fuel as in 87 octane fuel, so that he did not think that increased trouble need be expected except that due to the higher duty of the engine. Thus they would have to use Sinterkorund, which would not be attacked by lead, and concentrate on multi-points to cut down the rate of gap erosion.

One of the troubles with pure platinum was that it was attacked mainly at rich-mixture conditions in the engine, whereas it was comparatively immune from attack at weak-mixture conditions. The reason was that CO would go for platinum, and he believed that it suffered lead attack to a certain extent.

A quite serious trouble had been experienced with mica-insulated plugs in highly boosted aircraft engines. Sometimes, after engines had been idling on the ground in order to warm up, the squadron did not leave immediately, so that the engines continued idling. Under those conditions a considerable lead deposit might be built up, particularly if the engines idled for lengthy periods two or three times in a week. The deposit had good electrical resistance when cool, but this broke down when it (the deposit) was hot, so that a plug might fail and cause the engine to cut-out at a very dangerous period, *i.e.*, during the take-off. There was evidence to show that when a plug failed in that way it would cause a "fire-back" into the induction system and completely stop the engine. Plugs taken from an engine, which had stopped in this manner, had been tested under pressure for sparking, when cold, and had been found satisfactory; but when put back into the engine the same trouble had occurred. Of course, when plugs were suspected of having failed in this manner they must be cleaned before they were tested; having regard to the characteristic of the deposit.

Recently, when in Germany, he had seen a number of plugs with tungsten electrodes which had been used in high duty engines; having operated for periods up to 200 hours without removal for cleaning or adjustment. They were Sinterkorund insulated plugs having a central electrode of tungsten, or one of

high nickel alloy, and two simple electrodes pushed through to the side of the central electrode. The Siemens plug had a tungsten electrode, and the Bosch used a high nickel alloy; when the two types of plug were used in the same engine for the same period of running the gap erosion in the case of the nickel alloy electrode was somewhat greater than that found with the tungsten electrode. Although tungsten had a very high initial sparking voltage, its low erosion rate over a period of, say, 100 or 200 hours running, might be small enough to keep the voltage rise within reasonable limits, whereas those other materials having a relatively high rate of gap erosion might show a voltage increase almost equalling that of tungsten; so it seemed to him, and he asked for Dr. Bairsto's views on this, that from what he had seen of tungsten electrodes, they were rather to be favoured for some of the higher duty plugs.

Although reference had been made in the paper to the comparative ease of sealing the electrode in the Sinterkorund insulator, his own impression was that that was not so easy to do in practice, and that there was, at first, some difficulty in maintaining the seal between the electrode and the Sinterkorund under operating conditions.

There had always been an idea in this country that the American mica-insulated plugs behaved better than the British types, and he confessed that he had had the same impression. He had seen many (American) mica plugs after use in American engines, and they were in much better condition than British plugs in some British engines. But he gathered that the American engines ran at lower cruising speeds than ours, so that the gap erosion was considerably reduced, and he believed also that the Americans had paid much more attention than they had here to the placing and cooling of their plugs. This was particularly necessary when the N.A.C.A. type cowling was introduced. Recently some tests had been made with British plugs in American engines, and they had behaved most favourably in comparison with American plugs. Also the latter had been tried in British engines, but did not show up so well as they did in their own country's engines.

Mr. EMTAGE: The paper was a landmark or milestone in ignition history. A long time had elapsed since so comprehensive a work on ignition had been presented, summing up very adequately the present position and the problems with which they were endeavouring to cope. It was amazing that Dr. Bairsto had found time to collect so much information and to put it in the form in which he had presented it, having regard to the high pressure at which he was working at Farnborough.

Associating himself with the remarks of Mr. Banks concerning the positioning of the plugs, he said that not long ago an engine manufacturer had confessed to him that a standard plug would not go into the cylinder of a comparatively new engine, because there was not room for it. Perhaps he, personally, was a little biased on the side of the ignition maker; but he did feel that in modern times the designer of an engine, knowing what he did about ignition apparatus, the conditions in which the plugs worked and the restrictions which applied to the plug maker, should take advantage of the ignition maker's advice almost as soon as he put pencil to paper to design his cylinder. The plug maker or ignition maker should be in at the birth of the cylinder.

Although he had not been to America and had seen American engines only so far as they had been available in this country from time to time, he had the impression that the American engine was a little cleaner than the British and did not throw so much oil over the ignition apparatus; that trouble had been rather a handicap from the ignition point of view in the past, and he suggested that some little time and money might well be spent on that feature.

He had been told—though he did not know whether it was commonly known or was even accepted—that a leaky cylinder liner which allowed a little ethylene glycol to get into the cylinder would allow detonation to be reproduced and would even cut out; and that trouble might quite easily be attributed to ignition failure.

It had been the practice recently to lay at the door of the ignition maker almost any unexplained cut-out or failure. For example, quite recently someone had told him that he had discovered the cause of hitherto unexplained cut-outs on one type of fighter aircraft; and Mr. Emtage was particularly anxious to find a solution of that problem, for there had been fatalities as the result of some of those cut-outs. When he was told that the cut-outs were due to ignition failure he had asked whether they were due to the failure of the sparking plug, the leads, the magneto, or any other part of the ignition. His informer had replied that he was not referring to any particular part of the ignition system, but the point was that the mixture had failed to fire; in other words, there was failure of combustion. But the gentleman who had blamed the ignition was not sure that the right mixture was used. In such a case, when many people were anxiously seeking a solution of a problem, particularly where the users of the engines were running grave risks, it was easy to start a rumour that the ignition apparatus was at fault, even though that was not actually the case; many people were prepared to believe it.

Although he did not suppose that Mr. Banks was inimical to the ignition makers, he had set them a pretty problem when he had suddenly put into the hands of the engine designer a fuel which had put the engine ten years ahead; and the ignition makers were busy trying to catch up those ten years in as short a time as possible.

Commenting on the reference to the making of aluminium oxide insulators in Germany five years ago, he said he had first received intimation of the use of that material about six years ago and had mentioned it to Dr. Bairsto, who had said at once that it was good stuff; and he had asked for samples. Exactly a year had elapsed before the samples could be obtained from Germany, and a few more years were occupied in getting down to a production process, having regard to the complicated furnaces, and so on, which were required for production. But a great deal of credit was due to the plug makers for their enterprise in going to a great deal of trouble and expense to procure the necessary apparatus and to get the process working soundly.

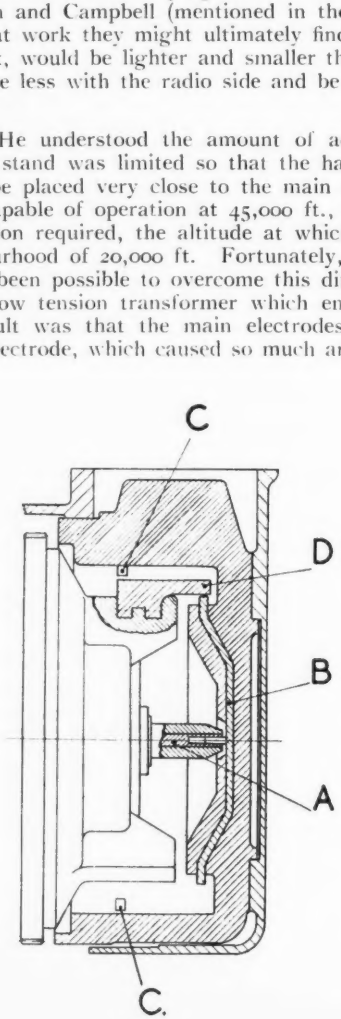
It would appear, he continued, that plug erosion varied a good deal with sparks of different qualities. In respect of coil ignition, a limited experience showed that under certain conditions the erosion was very considerably reduced. A point that had been brought to his notice in that connection—and he hoped that somebody who had been associated with the experiments would amplify his remarks—was that in at least one engine the plugs themselves seemed to be very much cleaner, *i.e.*, the actual amount of lead deposited was well below that ordinarily experienced with normal magneto ignition on the same engine. He could not think of a reason for that, because lead was deposited whether or not it reached a temperature at which it was fused. Mr. Banks had made it clear that lead that was deposited cold was not harmful; it was only when it reached temperatures of about 600° or more that it became lead oxy-bromide and served as a conductor. In that connection he recalled Mr. Banks' reference to plugs which had failed in an engine in ordinary operation, but had given good results when taken out and tested and had failed again when replaced in the engine. If lead had fused on them, one would have thought that they would have failed in the test; the fact that they did not fail then indicated that they needed to be heated before they would fail, that the lead oxy-bromide was a conductor only when hot.

Fig. 23 in the paper, showing part of a high tension distributor, and Dr. Bairsto's reference to the tendency to spark back to the preceding fixed segment as the rotor rotated, at low densities, by reason of the ionised path, led Mr. Emtage to refer to some troubles he had experienced in that connection. At one time, there had accumulated quite a large number of magnetos, which could not pass the ordinary laboratory acceptance test by reason of that trouble. Later he had taken a pair of rejected magnetos for flight test, and whereas they were

good for only 19,000 or 20,000 ft. altitude, as indicated by the low density box, they could operate at more than 30,000 ft. in the air. That had led him to suppose that the actual conditions at altitude were not exactly comparable with the simulated altitude conditions in a low density box, and he asked for Dr. Bairsto's opinion as to the reason for that—whether it was due to the increased dryness of the air in the sub-stratosphere, or whether there was an ionising effect due to cosmic rays breaking down the path between the brush and the fixed segment forward of the brush in the distributor.

Finally, in a reference to the new systems to which Dr. Bairsto had referred, and the exploration of the varying types and qualities of sparks, he suggested that they might find some type of spark more appropriate for igniting the mixtures of fuels used to-day than were the sparks which they had used for so many years. He believed there was in progress some further work, supplementary to that of Paterson and Campbell (mentioned in the paper), and he hoped that as the result of that work they might ultimately find a machine that, while giving an efficient spark, would be lighter and smaller than the present form of magneto, would interfere less with the radio side and be kinder to the sparking plugs.

Mr. A. M. Allen: He understood the amount of advance which a highly turbulent engine would stand was limited so that the hand starter electrode on the distributor had to be placed very close to the main electrode. Recently he had made a magneto capable of operation at 45,000 ft., but when the electrode was placed in the position required, the altitude at which it would operate was reduced to the neighbourhood of 20,000 ft. Fortunately, owing to an invention by Mr. Ramsay it had been possible to overcome this difficulty. This invention involved the use of a low tension transformer which energised the primary of the magneto. The result was that the main electrodes of the magneto were used, and the trailing electrode, which caused so much anxiety at altitude, could be eliminated.



Regarding the figures given for distance between electrodes in the distributor block, it had been found when obtaining data for new designs that the inductive trail from a discharge on a standard magneto was so extended that a distance of 42-45 mm. was required between segments. To overcome this difficulty he had introduced another gap in series with the main one to split the trail, as it were. Illustrating by means of a drawing the layout of the device, he showed that there was a stationary feeder coming through at A to a spider B moulded into the distributor block. This spider carries electrodes around its periphery which are all alive at the same time. Segments connecting the magneto with the plugs are shown at C. Electrode D moulded into the periphery of the distributor rotor connects up the spider and the appropriate plug segment in the distributor when the spark occurs. The result was that, with a distributor very slightly larger than the orthodox, operation at 45,000 ft. could be assured, without in any way interfering with the magneto coil. It is possible to reduce this trail by adding a high resistance or condenser in the winding of the coil, but these modifications give rise to other troubles.

Discussing the author's illustration of the German magneto, he said it was only fair to say that it was really a development of an invention by Watson, and it was an idea which has been used for many years in connection with motor cycle lighting and ignition.

Mr. H. E. WEST: He commented upon the reference, at the beginning of the paper, to sparking plug voltages of from 5,000 to 8,000, and said that experiments carried out by himself and his colleagues suggested that those figures were excessive. They had concluded that, as their experiments were made on rather more highly boosted engines, running at higher b.m.e.p. and higher plug temperatures, the higher plug temperatures had more effect than an increase of boost pressure in the cylinder. In their tests, modern plugs (K.L.G. RC. 1) with 0.012 in. gap gave voltages, under the worst conditions of polarity, of only 4,850 at 220 b.m.e.p. and 2,750 r.p.m.; and with 0.025 in. gap at the same powers, the maximum voltage recorded was only 6,400.

Cold starting voltages on the same plugs gave a maximum of 4,500 on 0.012 in. gap, and only 5,000 on 0.025 in. gap.

Confining his remarks mainly to coil ignition—because he had had quite a lot of experience on specialised coil ignition systems for aircraft engines during the last three years—he mentioned the author's statement of the claim that the voltage performance of a coil system of the orthodox type under conditions of capacity load and shunt electrical resistance was not as good as that of a well-designed magneto. He asked whether that statement related to a coil ignition system operated solely from a battery, because a coil ignition system operated from a generator or by some other method could easily produce the same performance as a magneto within the defined limits of operational characteristics. A magneto system at higher speeds produced an excess performance, and therefore, it was wasting its energy in producing excessive temperature rises and plug point erosion.

Expressing disagreement with the author's statement that the reliability of a system composed of coil, generator and battery was not as great as that of a magneto, he said he assumed the author was basing his assumption on the fact that the number of units was multiplied. In actual experience, however, which perhaps counted more than assumption, it was shown that the addition of another unit to the system did not necessarily render the system intrinsically less reliable; if the right materials were used and special care was taken in manufacture, the system could be just as reliable.

Dealing with the author's reference to the splitting up of the magneto parts in order to improve the accessibility of an engine, he said that when an engine was designed with a large number of cylinders and attempts were made to boost the engine within certain definite space limits, the ignition units presented a problem, and one purpose of the adoption of coil ignition by the Rolls Royce

Company was to make the design of the engine cleaner and to fit the ignition more symmetrically into the design. The coil ignition was designed when the design of the whole engine was at the drawing board stage, as was advocated by Mr. Emtage; by so doing, the whole system could be made very much better and more accessible. If the magneto, generator and distributor were split up, there was the same fundamental objection as there was to splitting up a coil, generator and distributor, because the number of parts was doubled and elements of difficulty in regard to timing were introduced. Where a magneto, generator and distributor were split up, the distributor had to be timed exactly to the magneto and generator contact breaker, which tied up the designer to placing the distributor spindle in exact time relation with the drive gears and drive spindle of the magneto and generator.

Reference was also made in the paper to elements of unreliability such as the possible damage by bullets to the various wires and associated parts of coil ignition systems as compared with magneto systems in military aircraft, and also the high transient voltages from the coil primary cables. Mr. West pointed out that the modern aero engine installation was vastly different from that of 20 years ago. Nowadays, the whole engine was literally festooned with electric wires, and in the future it would become even more festooned. In some installations there were as many as twelve electric wires going into the engine nacelles independently of the ignition wires. Thus, the addition of one or two further wires represented a very small percentage of the total. Further, with the double magneto system there were as many as six wires going out of the nacelle into the cabin. There would be high voltage transients if wires were broken during flight, or at any time when the engine was rotating.

With regard to the suggestion that the generator was a source of unreliability, he said that he and his colleagues had had quite a lot of experience with generators, totalling thousands of hours of running, and they held that the generator was nowadays the most reliable part of the whole ignition system. At one time they had thought that it might be the most unreliable part, due to the brushes, etc., but when attention was paid to brush gear design and methods of manufacture, and when the very best materials were used, the unreliability disappeared.

With reference to the erosion test carried out on A 2-2 plugs, no account seemed to have been taken of the polarity of the sparking plugs. The accurate measurement of erosion on a Lodge A 2-2 plug would appear to be a difficult matter and it was believed that far more accurate results could be obtained by using a single platinum wire earth electrode which could be removed after test for measurement, and a flat-topped nickel central electrode on which accurate measurement of the depth of erosion could be made. It was extremely difficult to measure plug point erosion, and he submitted that if a type of plug were chosen which rendered measurement more accurate, the results would be more reliable. In any event, the comparison of erosion on a plug of the A 2-2 type having a wide thick single electrode of annular gap where the spark might wander from point to point might possibly give erroneous results; further, it was considered that the test was not of sufficient duration.

Discussing the reference in the paper to comparative tests of erosion with magnetos and coil systems, in which it was stated that there was very little difference in the erosion obtained by either type of ignition system, Mr. West again submitted that the type of test was not representative of modern conditions. In the first place, the plugs used for the erosion tests were again A 2-2, so that they suffered from the disadvantages already mentioned. Secondly, the change of the plugs from one polarity to another at the end of each 10-hour period might possibly have produced an error in the final results, due to the fact that the plugs which eroded most during the first ten-hour period would ultimately have the highest erosion at the end of the test. In order to make a fair comparison, plugs should be kept at one particular polarity throughout the test. He and his

colleagues had made tests on three or four engines running for 100-hour periods, and had definitely shown reductions of 40 or 50 per cent. in the amount of erosion when coil ignition was used. Those tests were witnessed by accredited Air Ministry representatives.

Mr. W. E. Gough: Discussing the reduction of the after current in the magneto in relation to reducing plug electrode erosion, he said that in tests carried out by one engine manufacturer with magnetos which incorporated condensers in the secondary winding of such a value as to eliminate entirely the after current, it was found after 200 hours that the plug erosion was very little less with the condenser coil magnetos than with the standard magnetos. It had been found that the value of the condenser required almost to eliminate the after current was 0.002 microfarad.

The use of that value condenser brought with it other problems, however, which at the moment did not appear to be easily solved. The condenser itself contained a voltage after the spark had passed, and that voltage would cause a spark to pass across the plugs before the next spark was produced by the magneto, and pre-ignition resulted. That would not become evident on engines of relatively low speeds and where the magneto did not run above 3,000 r.p.m. because the inter-spark time was sufficiently long to allow the condenser partially to discharge. For higher speeds the time was reduced, and therefore, the condenser could not discharge. Another problem resulting from the use of the low value of condenser was that the distributor appeared over-stressed, and breakdown had occurred. He believed that to be due to the fact that the condenser voltage after the spark was in effect a D.C. one, and breakdowns occurred more readily with a D.C. voltage than with a peaky magneto voltage. He understood that the Bosch ZM 12 magneto incorporated a condenser of a value of approximately 0.015 microfarad; if that were correct, then it was not of much value for curtailing the after current. Also, of course, it would not show any tendency for pre-ignition, as the voltage across the condenser would be too low. The elimination of the after current in the magneto played a big part in the altitude performance of the magneto. A magneto with given leakage distances could have its altitude increased by as much as 7 to 10,000 ft. by the elimination of that after current.

Commenting on Dr. Bairsto's reference to some patents which had been issued by General Motors Corporation of the United States, where an alternator with a very peaky wave was used to charge a condenser which was discharged through a valve, he said he did not see how it would be possible, with a valve, to co-relate closely the position of the spark to the engine crankshaft, particularly as the discharge of the valve depended on the peak voltage, which peak voltage position, as Dr. Bairsto had said, retarded considerably with the increase in speed of the alternator. The particular patents to which Dr. Bairsto had referred had been tried out on American car engines, he believed, but not on aircraft engines. They might be successful on car engines which had quite low compression ratios and would, therefore, operate over quite a wide timing range without serious loss of power. Presumably the object of the patents was the elimination of contact breakers; and in that connection he said that the B.T.H. Company had made a magneto several years ago which operated without a contact breaker, but it had suffered in exactly the same way as the alternator in the General Motors scheme, *i.e.*, the position of ignition had retarded with the increase in speed and the results were not sufficiently consistent to enable an automatic timing device to be designed which would counteract that retarding of the spark.

(At this stage the President had to leave the meeting, and Mr. F. R. Banks occupied the chair.)

Mr. Scroggs: He would have liked to have heard more about the effect of different kinds of mixtures. At the beginning of the paper the lecturer had mentioned the effect of mixture on spark energy, but had rather left it at that, and

one could not help feeling that he had been assuming all through the paper that the mixtures used would be within the normal range of, say, from 12/1 to 15/1. It was rather important to think carefully about that matter, because it affected so much the reliability of the engine. As had been pointed out already, a momentary failure of either ignition or carburation in the modern supercharged engine could result in complete stoppage, and he personally had no doubt at all that that had caused a number of very serious crashes. If, therefore, the ignition system could be made to cope with a wider variation of mixture strengths, they had the means of compensating for the shortcomings of the carburation system. That might sound a little unfair; but if they could not make sure that the mixture was always correct—and it must be admitted that they could not—then they might be able to make up for it by using an ignition system able to fire a wider variation of mixture strengths. He believed it had become fashionable in the automobile world to use very much weaker mixtures, together with very wide plug gaps and voltages of the order of 20,000. On the other side, under take-off conditions, which apart altogether from the mixture were very severe on the ignition system, a very rich mixture was used. Such a mixture was by no means uniform, and if the average mixture strength were perhaps of the order of 9/1 it was quite possible that locally the mixture might be very much richer, and no doubt there was liquid petrol at times. He did not suggest, of course, that the plug should be capable of igniting petrol; but if it could fire a very rich mixture they might be able to overcome one possible source of failure.

With regard to coil versus magneto systems, probably on the whole there was not very much difference in respect of reliability. But with the coil system it was very much easier to diagnose a failure and it was very much easier to put things right, because one could get at everything quite easily and could change the defective part of the system.

It seemed that Dr. Bairsto was rather keen on cutting off the tail of the spark, presumably with the idea that it was the first spark that fired the mixture and that the rest did not matter. So long as they used normal mixtures, no doubt that was true; but was Dr. Bairsto satisfied that that remained true when using an abnormal mixture? He believed the motor car people had decided that, at any rate when using a very weak mixture, the first spark did not always fire it, and that it was rather a good thing to have a lot of nice fat oscillations following it. He asked for Dr. Bairsto's views on that.

Mr. F. R. F. Ramsey: He said that Mr. West's experience concerning the effect of temperature on plug voltage in high output engines rather coincided with his own, *i.e.*, the higher temperature in the high output engine tended to lower voltage rather than to raise it. The voltage characteristic depended to a considerable extent on the dimensions of the points of the plug. If those points were of such a type that they remained cool, plug voltage would probably increase as engine output increased; but if the plug points were of the type which increased in temperature, it was quite probable that the voltage would remain level or would decrease as the engine output increased. In an engine of which he had had a lot of experience the voltage remained level when the output was increased.

With reference to the effect of turbulence on plug voltage, he was of opinion that turbulence only affected the plug voltage indirectly, through the temperature effect. If increased turbulence tended to cool the plug points, the voltage would increase, but the actual blast of gas did not affect the striking voltage. He felt that there was a good deal of misapprehension on this point, though he did not suggest that it was shared by Dr. Bairsto. The velocity of the ions in the electrostatic field between the plug points before the spark jumped was too great to be affected by any gas blast likely to exist there, although the arc afterwards established by the spark could be blown out. The simplest test of this was to measure the peak voltage across a rotary spark gap. It would be found that the voltage would not increase with the speed, and he had found that it actually tended to decrease.

Discussing the curve relating increase in plug gap with various values of series resistor, he uttered a warning against using the higher values of resistance. The knee of the curve, with both screened and unscreened cables, came at very approximately 1,000 ohms, *i.e.*, the increase in gap burning became very rapid with values less than 1,000 ohms, and with values of more than 1,000 ohms the gain improved very slowly. The reason for not using less than 1,000 ohms was obvious, but it was not obvious why higher values should not be used; indeed, Dr. Bairsto had mentioned a value of 2,000 ohms.

The first phase of the general investigation by all concerned with series resistors was concentrated upon resistors of 10,000 ohms and more in value, probably following upon the use of such values as interference suppressors in automobile engines. That phase had closed with the practical abandonment of resistors for use in aero engines owing to an unforeseen disadvantage which had appeared in the course of engine tests. That was the building up on the points of the gap of deposits from the burnt fuel, which closed, or nearly closed, the gap in the course of time, and put the plug out of action.

His own investigations into the subject had followed that phase, but were concentrated upon reducing the rate of discharge of the cable capacity rather than upon attempting to eliminate high frequency oscillations, which would seem to have led some of the earlier investigators astray. The new investigation had led to the 1,000 ohm resistor, now manufactured by K.L.G. under his patent. An upper limit of resistance value was specified in that patent; the reason was that he had found, when making engine tests, that the gap closing phenomenon made its appearance with quite low values of resistance, particularly when running at high boost and with the higher octane fuels. A value of 2,000 ohms was quite sufficient for the trouble to make its appearance.

The 1,000 ohm resistor gave a spark having a very similar appearance to that obtained with an unscreened cable, and it would seem that any considerable increase in the damping of the capacity discharge to below that value resulted in there being insufficient energy to burn away deposits in the gap.

It was possible that that trouble would re-appear with some of the new experimental ignition systems now being developed, if the type of spark which they gave was very different from the normal magneto spark. Only extended engine tests under the right conditions would serve to make that point clear. However, it would be well to bear the point in mind.

Mr. KLEYNOT: He asked for Dr. Bairsto's views on the ignition system with a low voltage transmission, mentioned in section 4 of the paper, under the heading "Other Types of Ignition Systems." From the aero engine manufacturers' point of view, he said, that subject was of great interest. When it was considered that the weight of magnetos, high tension wire harness, sparking plugs, etc., on radial engines of 9 cylinders was approximately 60 lbs., and on engines of 14 cylinders it was about 70 lbs., and so on, it would be appreciated that anything which would tend to reduce the weight, as would a low voltage distributing system, would be of great value. In the course of some simple preliminary tests carried out recently on a system with a low voltage A.C. distribution and transformers at the sparking plugs, it had been proved that plug erosion was reduced by approximately 50 per cent.; indeed, it was slightly lower than with coil ignition.

Mr. L. W. JOHNSON (*Associate Fellow*) (*communicated*): In view of Dr. Bairsto's reference to the use of platinum metals and their alloys as electrodes for sparking plugs, and his statement that the best results are being obtained with platinum-iridium alloy containing 20 per cent. iridium, the results of trials carried out by the Bristol Aeroplane Company, in co-operation with the Mond Nickel Company, may be of interest.

Pure platinum, pure rhodium, pure iridium, 20 per cent. iridio-platinum and 20 per cent. rhodio-platinum were used in the form of 0.02 in. diameter wire as

earth electrodes in a 6-wire type of plug with austenitic steel as central electrode. In rich mixtures the order of merit as judged by resistance to gap erosion was:—(1) 20 per cent. rhodio-platinum, (2) pure rhodium (not sufficiently ductile), (3) 20 per cent. iridio-platinum, (4) pure platinum. Iridium was good, but too brittle to permit any adjustments. In weak mixtures pure platinum was the best and 20 per cent. rhodio-platinum was again superior to 20 per cent. iridio-platinum.

The final choice of electrode material may, however, be governed by other considerations rather than that purely of resistance to gap erosion, and while pure iridium and pure rhodium cannot be used owing to brittleness, the choice between rhodio-platinum and iridio-platinum may be influenced by the higher strength of the iridio-platinum.

There is no reason for thinking that the superior resistance of rhodio-platinum to gap erosion is limited to the 20 per cent. rhodio-platinum, and tests have in fact shown that 10 per cent. rhodio-platinum is equally satisfactory. In special circumstances where sulphur attack may occur, as when high sulphur fuels are used, it may be preferable to use $3\frac{1}{2}$ per cent. rhodio-platinum which is not embrittled by exposure to sulphur at temperatures up to 1,100°C.

Reply to Discussion.

He would first deal with attack by fuels on electrode materials. Molybdenum was the only material he had found to be attacked by T.E.L. fuel. Platinum was definitely attacked in certain gases. Reference was made in the paper to inter-granular separation of platinum when heated in a carbonaceous atmosphere; but the trouble was complicated by the strain. In some cases, as the result of reinforcing the electrode the trouble had been overcome.

The reference made by Mr. Banks to the use of tungsten was of great interest. He and his colleagues had not obtained figures such as those mentioned by Mr. Banks as having been obtained in practice, where the gap erosion of the nickel electrode was about 50 per cent. more than with tungsten; but perhaps in their tests the engine b.m.e.p.'s and speeds were different from those obtained in the case referred to by Mr. Banks. There might also be effects due to differences in the design of the other parts of the electrode system. It might be that the discharge had spread itself circumferentially round the gap.

The sealing of electrodes in the insulators was not easy, and he had with him a few records concerning certain plugs which had given rise to trouble in their early stages of development. But time tests nowadays for gas leakage were giving very good results. Some of the early plugs had used copper washers, but they had not lasted long, because the T.E.L. fuel had attacked the copper. But a soft iron or steel washer, fitted so that it acted as a small spring, was very helpful.

He agreed entirely with Mr. Emtage that the ignition equipment should be given proper consideration before the design of an engine proceeded too far. Too often different items of the ignition system had been handicapped simply because an engine was more or less standardised.

With regard to the criticisms concerning the erosion tests described in the paper, he said that he had deliberately used the modified A 2-2 type plug electrode in order to obtain accurate results, and he assured Mr. West that the results were quite beyond question.

Dealing with the points raised by Mr. Gough, the A.C. system produced by the B.T.H. Company had been under test at R.A.E. for a short time. After 20 hours' engine tests with unscreened cables there was just about half the erosion which occurred with a magneto, and with screened cables it was just a little less than half. But if a screened alternator system were compared with a standard magneto with a resistance of 1,000 ohms, the resistor won.

He had not yet tested the Bosch system for electrode erosion performance, but the system had certain interesting points. It was many years since he had

worked out roughly what the performance of a standard magneto with series condenser would be, and he concluded that it was necessary to have at least 1,000 micro-microfarads, otherwise the voltage would be so low that one could not make anything of it. But apart from that, the greater the series capacity the smaller the frequency of the oscillation which built up the spark, and this mathematical analysis had shown that the magnitude of the series condenser, when it reached 1,000 micro-microfarads, together with the secondary inductance absolutely controlled the frequency. The reduction in frequency of the oscillation caused a big reduction in performance of the magneto under shunt resistance conditions.

The condenser system had a curious effect. It actually gave a lot more positive and negative discharges. Indeed, the number of negative sparks on the other side of the time axis was almost as great as the positive; but the sum total of them was less than in the magneto. If a resistance were inserted the negative sparks largely disappeared. However, the tests had not been carried very far yet and he would have more to say about them later on.

With regard to the differences in the results obtained with coil and with magneto ignition, he was quite prepared to believe that, as was rather implied by Mr. West, the different conditions in different modern engines might account for them. But when tests were made on the same engine, with the same polarity and every other condition carefully controlled, he had found very little difference between the two systems, where screened cables were used. Sometimes there were curious results, and it was quite obvious from the complicated mechanism of discharge that the effect could go one way or the other. There were cases in which the results with the coil were actually worse than with the magneto. The polarity and a host of factors affected the results; but if one compared the two systems under identical conditions, making sure one was not being cheated by some particular uncontrolled effect, it would be found that his statements in the paper were substantially correct.

Discussing the reference by Mr. Emtage to the performance of magnetos at high altitudes, he referred back to Fig. 19 in the paper, which showed the variation with altitude of the sparking plug voltage in an engine with the voltage of alternative paths in the magneto. The reason why some of the magnetos, which in type tests, had been cleared for an altitude of only 19,000 ft., whereas the engine would go up to 30,000 ft., was simply that the full line curve in Fig. 19 for the engine was at a considerably lower level than the dotted line curve. There were no obscure and complicated effects due to the cosmic rays. It had been suggested that in the ordinary laboratory tests the air was not in quite the same condition as the air in the substratosphere. There was nothing in that at all, however. The point was simply that the curves giving the performance of plugs and magnetos at altitude were crossing at points which were different from those which had been preconceived. It was quite a simple matter and there was nothing subtle about it.

The problem of performance at high altitude had been referred to in rather different form by Mr. Allen; but he assured Mr. Allen that it was perfectly possible to modify any of the standard magnetos, bearing in mind the various principles given in the paper. Taking account of the data obtained, one could re-design the magnetos to increase the safe altitude of operation to 45,000 ft., without any trouble whatever; it could be done without introducing any fancy and elaborate design problems.

Mr. Allen had quoted a figure of 42-45 mm. for the minimum distance between distributor segments to secure the necessary performance of 6,000 volts at 45,000 ft. It is of interest to note that a distributor can be designed to give that performance at intersegment distance as low as 35 mm. The suggestion made by Mr. Allen was quite ingenious and interesting, but it was perhaps unnecessarily complicated. He thought that the increased performance which might be obtained

by its use would be small in the case of a distributor otherwise designed to give maximum performance. It should also be noted that the scheme was only applicable to magnetos having fixed timing.

He agreed with Mr. West that in some of the modern engines the voltages tended to be lower than those quoted at the beginning of the paper. But he was not so sure that in some cases the figure might not be getting rather too low. But the matter was rather *sub judice* at the moment and he did not wish to go further into that. The figure of 5,000 volts with a 0.012 in. gap, at 220 b.m.e.p., quoted by Mr. West, was not far from that quoted in Section 1 of the paper, of 4,500 to 4,800 volts. The Dagger engine was of very high b.m.e.p. and the voltages given in Fig. 1 of the paper, which voltages were measured from a Dagger unit, had a definite significance which could not be ignored.

As to the various points raised by Mr. West concerning coil ignition versus magneto systems, Dr. Bairsto said that in the paper he had considered the pros and cons and had weighed them as well as he had been able, and he had concluded that it was more a matter of expediency, of overcoming difficulties in providing room for the ignition gear. He was still convinced that the proposition of using a coil system was by no means so simple as had been thought.

Mr. West had put some queries on the relative performances of coil ignition systems and magnetos. A careful study of the curves given in Figs. 27 and 13 will show that a battery and coil system (with of course the usual associated generator) gives a very poor performance and that if a self-regulating generator of the type described in the paper is used, although a much better performance can be obtained, it is still below that of a well-designed magneto.

On the question of reliability, Mr. West had referred to the effect of damage by bullets, and in particular to the low tension cables. It should be pointed out that, if the primary circuit of a magneto were shot away, no harm would arise as that circuit was not carrying current when the magneto was in operation. It only carried current when the primary switch was closed, whereas in the case of a coil system if the primary circuits were interrupted, ignition would cease.

As to the reliability of the generator, he was still not sure that we had really reached a 500-hour service, and it would be very interesting if Mr. West could give a time basis for that reliability. For example, one could not expect the brushes of generators to last for more than a limited time. Whoever tackled the problem of coil ignition versus the magneto would find that his own particular sphere of activities would determine his viewpoint.

Commenting upon Mr. Gough's reference to the Bosch ZM 12 magneto incorporating a condenser having a value of approximately 0.012 microfarad, he said that that seemed an extraordinarily and unnecessarily high figure, about 0.002 was sufficient. The figures quoted in the paper dealt partly with Mr Gough's point with regard to the A.C. scheme, but he had no data on the condenser scheme.

A number of interesting points with regard to mixture strengths had been raised by Mr. Scroggs, who would no doubt appreciate that if a very wide range of mixture strength was to be covered the difficulties with regard to alternatives to magnetos would become greater than ever.

Work additional to that of Paterson and Campbell was being carried out, and the whole question of the relationship between the type of discharge required and mixture strength over a reasonably wide range was being investigated. In Fig. 2 the curves tended to be asymptotic at a value of about 4,000 volts; although it had been proved that they covered all normal ranges of mixture concerned, he believed that the curves for the very weak and very rich mixtures must be well outside the particular curves shown if the modern magneto could not cope with them. For example, the top curve in Fig. 2 was 0.007 joules per spark at 5,000 volts, and magnetos giving nearly ten times that could easily be made. Again, the factor of joules per spark was not the only one which determined the

firing of the mixture. The degree of turbulence, for example, was very important, but we did not know how important were various other factors associated with the nature of the discharge.

Replying to the points raised by Mr. Ramsey, undoubtedly the temperature of the plug electrode points is important, but the temperature of the gaseous mixture near the electrodes might have a very close correlation with the erosion effects. The reduction in the spark voltage in high output engines instead of an increase might be taken as an indication of more or less undesirable plug design.

He assured Mr. Ramsey that there should be no misapprehension about the effect of turbulence on spark voltage. Turbulence did definitely have an effect, quite independently of change of temperature.

I cannot follow all Mr. Ramsey's remarks on the application of series resistance in reducing plug electrode erosion. In our extensive range of experiments at R.A.E. we have met no adverse results which set an upper limit to the value of the resistance. There is no particular virtue in the value of 1,000 ohms as suggested. I believe that the phenomenon referred to of gap closing, due to "deposits from burnt fuel," must be associated with rich mixtures.*

The low tension system, mentioned by Mr. Klevnot had an attraction in the single cylinder unit, but although he had no experimental information he felt that it might not be so attractive when applied to a complete multi-cylinder engine, because it involved a transformer at each plug; and the problem of reliability under the difficult temperature conditions again arose. However, the scheme was *sub judice* at the moment and must be tried out.

Mr. Johnson's remarks on electrode materials in the class of rare metals are of considerable interest, in particular the reference to rhodio-platinum. From data in his possession it appears that the tensile strength of 10 per cent. Rh-Pt is about 50 per cent. higher than Pt-Ir at very high temperatures. There is scope for a considerable amount of work on the rare metal alloys of both binamy and terneny systems.

At the conclusion of the discussion a hearty vote of thanks was accorded Dr. Bairsto.

* Since the paper was read a series of tests have been made on the Dagger III, the engine presumably to which Mr. Ramsey refers. It was found that building up of electrodes of platinum-iridium alloy is accelerated by the use of a rich mixture associated with a cold running cylinder. The effect was, however, not appreciably different with 5,000 ohms or 1,000 ohms resistor. D.T.D. 230 fuel was used with both K.L.G. R.C. 41 and C.41-D plugs.

RIGOROUS PERFORMANCE PREDICTION WITHOUT DRUDGERY.*

By Elliott G. Reid.

Summary.

A new graphical method of predicting aeroplane performance has been evolved by utilising the unique properties of Eiffel's logarithmic propeller chart. Its substitution for rigorous numerical methods results in the saving of labour without sacrifice of accuracy. Particularly convenient when constant speed propellers are involved, this method yields performance characteristics for altitudes below, as well as above, the critical ones for supercharged engines.

Although coupling of the word " rigorous " with any method of aeroplane performance prediction may be somewhat of a misnomer, the title of this paper is intended to identify a method which falls short of complete rigour only to the extent dictated by acceptance of the following simplifying assumptions:—

(1) That the propeller thrust acts along the direction of the flight path, and
(2) That lift is equal to weight in steady rectilinear flight.

The amount of labour involved in predicting the performance of a modern aeroplane with even this degree of rigour is so great that methods which incorporate additional simplifying assumptions[1] have come into common use—despite their sacrifice of accuracy to convenience—and the more laborious methods are now rarely employed except in studies of very painstaking character. The desirability of minimising the drudgery of rigorous prediction has long impressed the writer and it is the purpose of this paper to describe a graphical method of attaining that objective.

The principal departure which characterises the new method is the adaptation of Eiffel's logarithmic propeller chart to the construction of available power curves. The use of " indicated airspeed " ($\sigma^{1/2}V$) and the analogous quantity " indicated power " ($\sigma^{1/2}$ h.p.) as co-ordinates causes a single curve to represent the power requirements for level flight at all altitudes. Other simplifications arising from the recognition of certain engine characteristics, utilisation of the unique properties of the Eiffel chart and development of a convenient method for evaluating the excess available power (from logarithmic curves) make it possible to eliminate a large portion of the labour previously required for rigorous performance prediction. The method is not only applicable to, but especially convenient in, the case of the constant speed propeller; moreover, it yields complete level flight and climb characteristics for altitudes below, as well as above, the critical altitudes of supercharged engines.

Description of Method.

It will be convenient to divide this description into two parts in order that the distinctly different problems presented by aeroplanes equipped with fixed-pitch and constant speed propellers may be dealt with individually.

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* Paper presented at the Annual Meeting of the Institute of Aeronautical Sciences Inc. on January 27th, 1939, and published by kind permission of the Editorial Board of the Institute and the author.

[1] Constant torque engine, idealised curves of required power, generalised propeller efficiency curve, empirical r.p.m.-airspeed relations, etc.

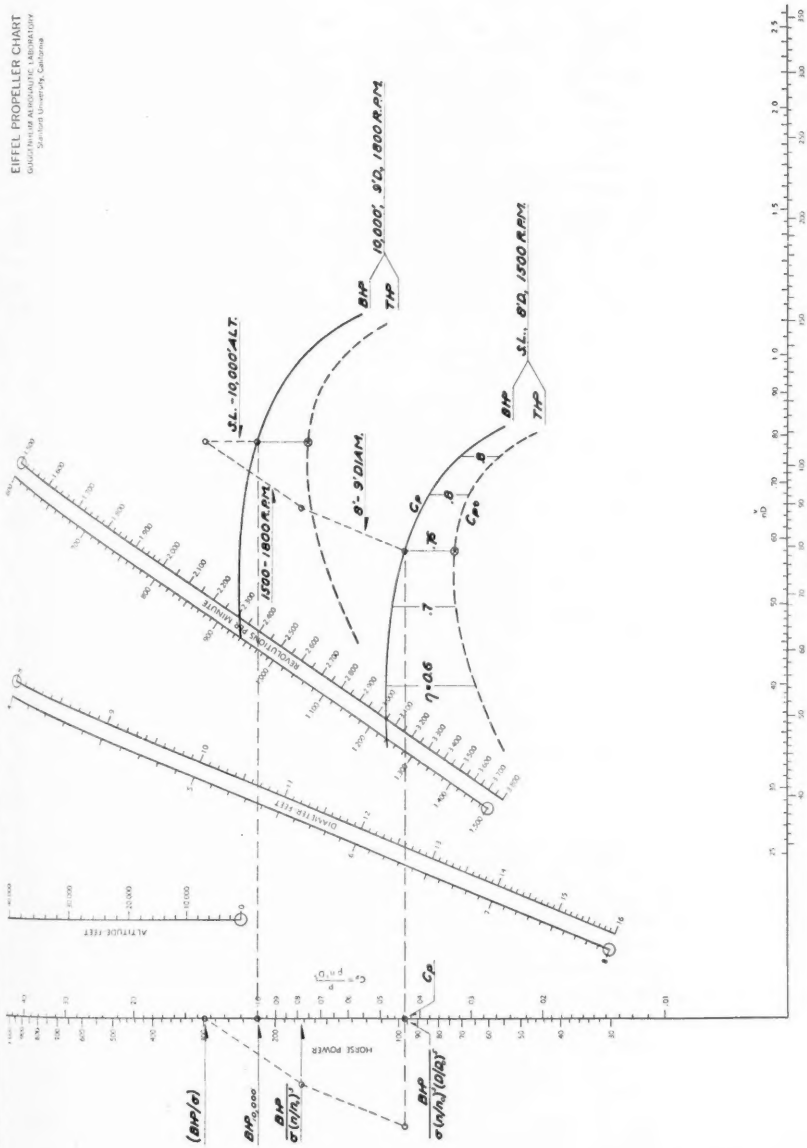
EIFFEL PROPELLER CHART
VELOCITY-MILES PER HOUR
ALTITUDE-FEET
DIAMETER-FEET
HORSE POWER
R.P.M.
BHP
THP
SL.-10,000 ALT.
SL., 8'D, 1800 R.P.M.
SL., 8'D, 1500 R.P.M.
8'-9" DIAM.
1500-1800 R.P.M.
η·86

FIG. 1.

1. Fixed (Adjustable) Pitch Propeller

Fig. 1 illustrates the properties of the Eiffel logarithmic propeller chart[2] upon which the method is based. It will be seen that the sea-level curves of b.h.p. absorbed and t.h.p. delivered by a propeller of given form and size undergo simple rectilinear displacements as the result of variations of diameter, r.p.m. and altitude. (The displacements of both curves are identical; their directions are those of the diameter, r.p.m. and altitude axes.) The broken line construction in the left-hand margin illustrates the equally important fact that the power coefficient which corresponds to given values of b.h.p., D, N and altitude may be determined by laying off the reversed displacement vectors from the appropriate point of the power scale. Combination of these two graphical procedures enables direct determination of the thrust horse-power and the air speed at which it is delivered when propeller characteristics and engine operating conditions are known. Fig. 1 thus illustrates the solution of the following problem:—Find the air speed at which a 9 ft. propeller of given form characteristics defined by lower pair of curves—C_P and C_{Pt} vs. V/nD)—will absorb 221 b.h.p. at 1,800 r.p.m. at 10,000 ft. altitude and determine the corresponding value of t.h.p.$_a$. The results are 106 m.p.h. and 168 t.h.p.

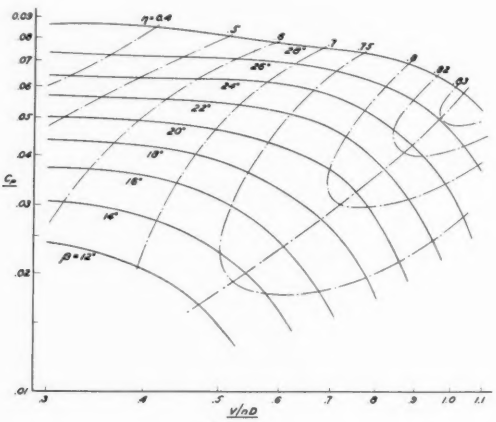

Fig. 2.

For use in this method of prediction, propeller data must be plotted in the form illustrated by Fig. 2. A pair of such charts corresponding to two- and three-blade propellers of current types will suffice for solution of the great majority of present-day performance problems because the effects of normal variations of interference can be represented, within the limits of propeller test accuracy, by rectilinear displacements of the curves, *i.e.*, they are displaced without sensible distortion or rotation.

The first step in the preparation of the available power curves is to draw upon the performance chart—Fig. 3— the curves of C_P and C_{Pt} versus V/nD for the propeller which is to be used. The C_P curve may be transferred from Fig. 2 to Fig. 3 by superimposing the former upon the latter and pricking through the intersections of the efficiency contours with the appropriate C_P curve. Then, since $C_{Pt}=\eta C_P$, the C_{Pt} curve is defined by laying off, below each of the transferred points, a distance corresponding to the local value of η (*e.g.*, when $\eta=0.5$,

[2] For complete theory and development, see Reference 2; a brief description appears in Reference 3.

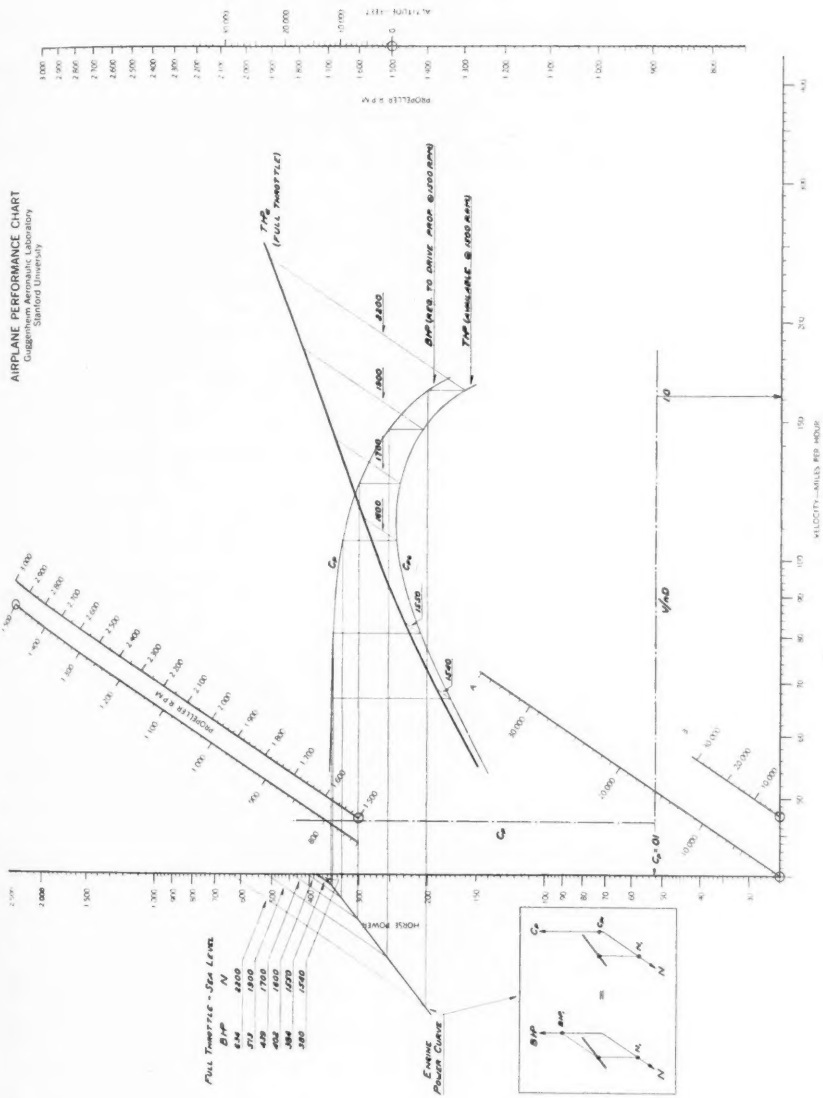
AIRPLANE PERFORMANCE CHART
Guggenheim Aeronautic Laboratory
Stanford University
THP (FULL THROTTLE)
BHP REQ'D TO DRIVE PROP @ 1200 RPM
THP (AVAILABLE @ 1200 RPM)
HORSE POWER
VELOCITY - MILES PER HOUR
Cp
Cx
Cz
Cx/Cz
V/VMD
FULL THROTTLE - SEA LEVEL
N
BHP
1200
1300
1400
1500
1600
1700
1800
1900
ENGINE POWER CURVE
BHP
N

FIG. 3.

the distance is that between 100 and 50 h.p.). Two calculations are required to locate Fig. 2 upon Fig. 3; they are:—

$$V \text{ (at which } V/nD = 1.0) = 0.082\ n_o D \quad . \quad . \quad . \quad . \quad (1)$$

$$\text{h.p. (at which } C_P = 0.01) = 0.01\ \rho_o n_o^3 d^5/550 \quad . \quad . \quad . \quad (2)$$

in which n_o corresponds to the reference point of the "propeller r.p.m." scale, *i.e.*, $n_o = 1,500/60 = 25$, ρ_o is sea-level air density and D is the diameter of the selected propeller.

The next step is to plot the speed-power characteristics of the engine upon the performance chart. A typical sea-level full-throttle power curve for a modern aircraft engine appears in the left-hand margin of Fig. 3.[3] The method of plotting the data and the dual significance of this curve will become evident upon reference to the appended data and auxiliary sketches.

We now have sufficient data to construct the sea-level full-throttle curve of t.h.p.$_a$ versus V. The procedure is as follows:—From an arbitrary point of the C_P curve, horizontal and vertical lines are extended to the curves of engine power and C_{Pt}, respectively. From the intersection of the vertical with the C_{Pt} curve, a line is drawn parallel to the N axis and along it, the "N vector" is laid off. (The "N vector" is the distance—along the direction of the r.p.m. axis—from the intersection of the horizontal line and the power curve to the h.p. axis.) The point so determined (above the C_{Pt} curve if the r.p.m. is greater than 1,500 and below if it is less) is a point of the t.h.p.$_a$ versus V curve—which, at sea-level, is identical with that of $\sigma^{1/2}$ t.h.p.$_a$ versus $\sigma^{1/2} V$. A few repetitions of this process suffice to define the curve throughout the speed range of the aeroplane.[4]

The construction of available power curves for full-throttle operation at altitudes above sea level is illustrated by Fig. 4. The curve of b.h.p. versus N for 25,000 ft. will be seen low in the left-hand margin. To transform it into a curve of C_P versus N, we must multiply its ordinates by ρ_o/ρ 25,000, *i.e.*, by $1/\sigma$, because C_P varies inversely with σ. This is accomplished graphically by elevating the engine power curve by the distance between the 0 and 25,000 ft. points of the altitude scale (right-hand edge of chart). Thus, the broken line designated "b.h.p./σ versus N, 25,000 ft." is the curve of C_P versus N for that altitude. Using this curve, the 25,000 ft. t.h.p.$_a$ versus V curve (broken line) is now obtained by following the method illustrated in Fig. 3 and adding to the process a downward displacement of each point through the distance identified by the dimension "σ." (In Fig. 1, the analogous displacement is designated "S.L.—10,000 ft. alt.") To transform the t.h.p.$_a$ versus V curve into one of $\sigma^{1/2}$ t.h.p.$_a$ versus $\sigma^{1/2} V$, the former must be shifted downward and toward the left[5] by amounts corresponding to the multiplication of its ordinates and abscissæ by $\sigma^{1/2}$. As shown in Fig. 4, these displacements are unequal because the modulus of the V scale is twice that of the h.p. scale.

Examination of the foregoing process of construction reveals the following relationship between the sea-level and altitude curves of full throttle $\sigma^{1/2}$ t.h.p.$_a$ versus $\sigma^{1/2} V$. When measured in the direction of the r.p.m. axis, the distance between the two curves is the same at all points. This may be confirmed by reference to Fig. 4 where the distance is divided into the two components "$\sigma^{1/2}$, $\sigma^{3/2}$" and "A." The former depends only upon altitude; the latter is constant for any given altitude because the uniform effect of air density upon full-throttle power output at all engine speeds results in parallelism of the rectilinear b.h.p./σ versus N "curves" for all altitudes. Thus the full-throttle power available curves for all altitudes are seen to be simply displaced replicas of the corresponding sea-level curve.

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[3] Figure 16 shows that such "curves" deviate negligibly from rectilinear form.

[4] A 30°-60° triangle re-cut to the slope of the r.p.m. scale (3:2) is convenient for drawing "rev-lines" and, when used as a guide for setting dividers, eliminates the drawing of many lines which might become confused.

[5] The same h.p. and V scales are used for plotting both "true" and "indicated quantities

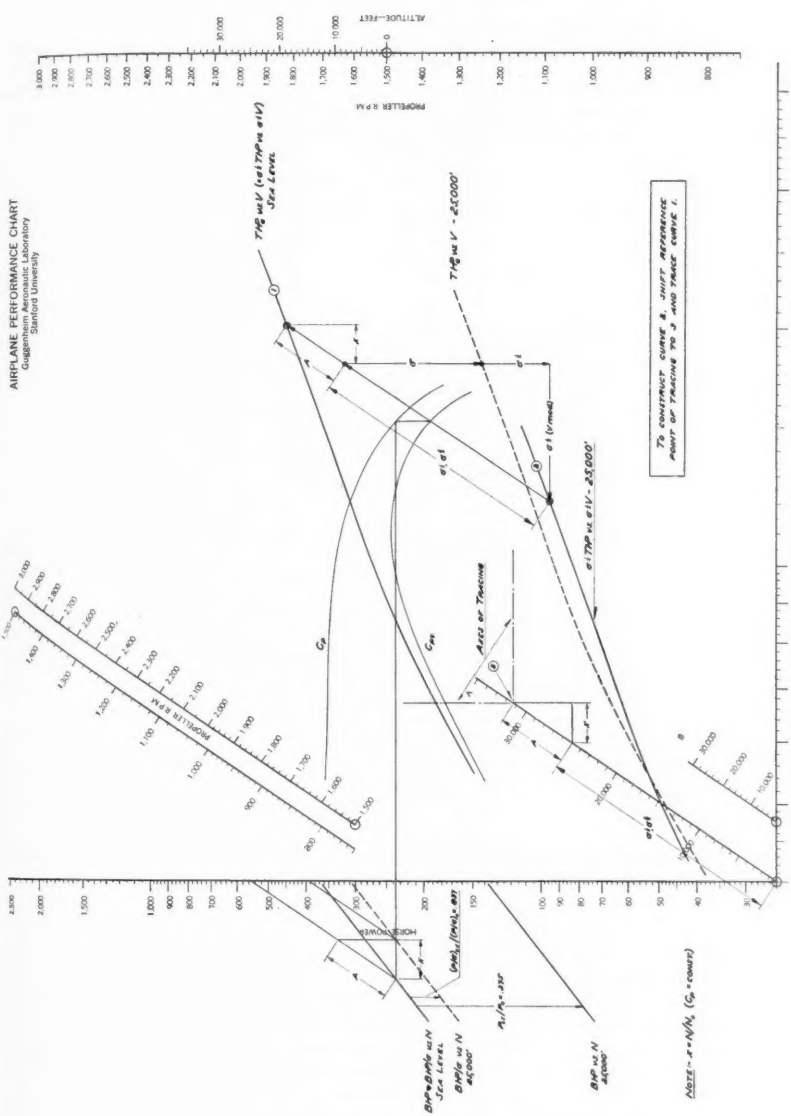
AIRPLANE PERFORMANCE CHART
Guggenheim Aeronautical Laboratory
Stanford University
ALTITUDE—FEET
PROPELLER R.P.M.
VELOCITY—MILES PER HOUR
HORSEPOWER
TO CONSTRUCT CURVE 8, SHIFT REFERENCE POINT OF TRACING TO 3 AND TRACE CURVE 1.
Area of Tracing
NOTE - σ = N/N₀ (Cₚ = const.)

FIG. 4.

The discovery of this relationship suggests a convenient method of constructing the full-throttle curves of available power for all altitudes. Superpose a sheet of tracing paper upon the performance chart and trace the axes and the sea-level curve of $\sigma^{1/2}$ t.h.p.$_a$ versus $\sigma^{1/2}V$; to construct the curve for any other altitude, shift the tracing sheet—in the direction of the r.p.m. axis—through the distance appropriate to that altitude and retrace the sea-level curve. The displacement of the tracing appropriate to an altitude of 25,000 ft. is illustrated in Fig. 4. Scale Λ is parallel to the r.p.m. scale and defines that component of the displacement which depends only upon air density; for convenience, it is calibrated in terms of altitude rather than density. The other component of the displacement, *i.e.*, that defined by x, the horizontal distance between the b.h.p./σ versus N

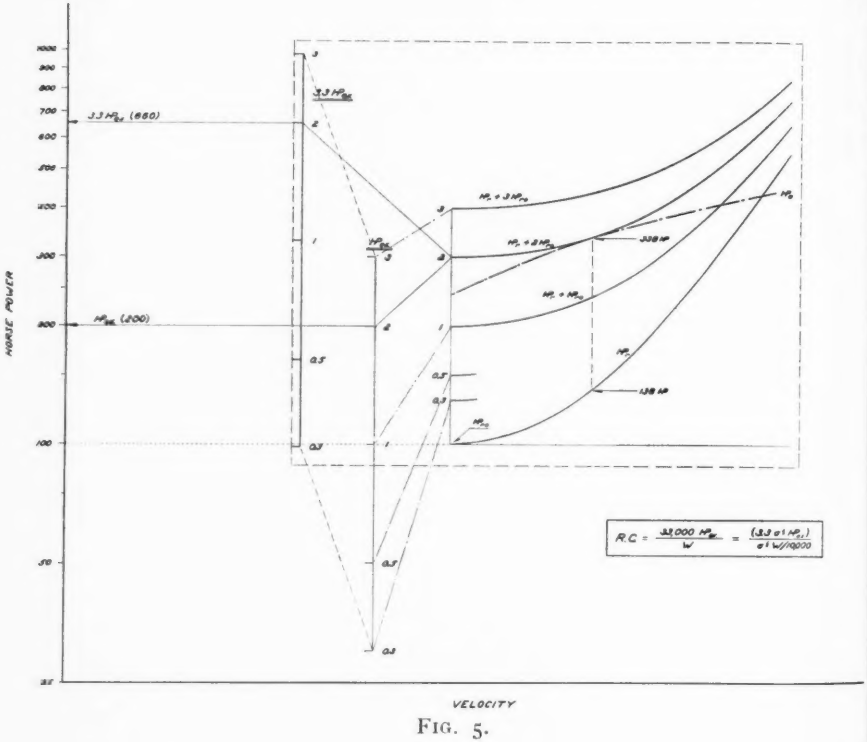

FIG. 5.

curves, depends upon power plant characteristics and must therefore be evaluated individually for each type of engine.

Since the available power curves corresponding to the limited engine output allowable for normal climb and cruising operation are obtained by similar methods, their construction will be illustrated by an example which involves a supercharged engine. However, to avoid subsequent digression, this will be prefaced by a description of the method of evaluating the rate of climb.

An idealised curve of power required at sea-level (h.p.$_r$) is shown in Fig. 5; above it are curves whose ordinates exceed its own by integral multiples of the *minimum* required power, h.p.$_{ro}$. Since the illustrated curve of h.p.$_a$ is tangent to the curve whose ordinates are h.p.$_r$ + 2 h.p.$_{ro}$, the maximum excess power available for climb is, in this case, 2 h.p.$_{ro}$, or 200 h.p. The illustrated connection

between the curves, the logarithmic scale designated h.p.$_{ex}$ and the h.p. scale of the performance chart indicates that if a family of suitably shaped curves (on a transparent sheet) could be superposed upon the available and required power curves for a particular aeroplane, the maximum h.p.$_{ex}$ could be determined by inspection and projection from the h.p.$_{ex}$ scale to the h.p. scale of the performance chart. For altitudes above sea level, the results would be obtained in terms of indicated power ($\sigma^{1/2}$ h.p.$_{ex}$). The fact that actual t.h.p.$_r$ curves closely approach the idealised form[6]—which is invariable when plotted in logarithmic co-ordinates—makes this a practicable method for accurate evaluation of rates of climb. The curves and a properly related logarithmic scale have been reproduced by printing on a rectangular blank of clear Plastacele; its dimensions are indicated by the dashed outline on Fig. 5. To reduce the vertical dimensions of the blank, the scale has been so shifted that it identifies the value of 3.3 $\sigma^{1/2}$ t.h.p.$_{ex}$; this also eliminates one slide rule operation in calculating the rate (see equation, Fig. 5).

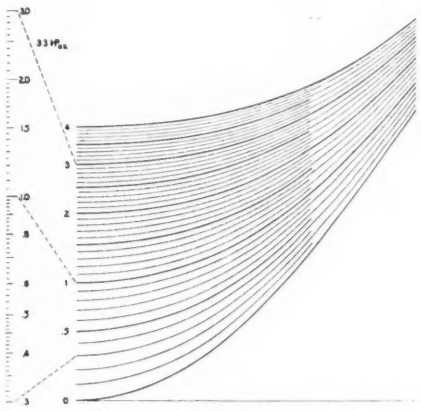

FIG. 6.

Fig. 6 is a photograph of the transparent " climb chart "; the only precaution which must be observed in using it is to make sure that the base curve is *tangent* to, if not *coincident* with, the actual required curve at the abscissa at which the excess power is evaluated.

EXAMPLE.

The aeroplane chosen for purposes of illustration is a low-wing, four-place, cabin monoplane of 5,300 lbs. weight; the engine is a direct drive type rated 555 b.h.p. at 2,200 r.p.m. and 7,600 ft.; and the two-blade propeller, of 9.5 ft. diameter, is set at 25° (see Fig. 2). The prediction is begun by transferring the C_p curve from Fig. 2 to the performance chart, Fig. 7, and constructing the corresponding C_{pt} curve. Next, the sea-level curves of b.h.p. versus N for full throttle, climbing (33 in.—2,200) and cruising power (27 in.—2,000) are plotted in the left-hand margin. Corresponding curves of t.h.p.$_a$ versus V are then constructed. (Only a short segment of the " cruise " curve need be drawn because climb at such low power will not be of interest.)

To construct the altitude curves of available power, the " additional displacements " (analogous to " A," Fig. 4) must be determined for each altitude and

[6] See Reference 4; equation: h.p.$_r$=h.p.$_{ro}$ $(0.75/r+0.25\,r^3)$ ($r=V/V_o$; V_o is the speed for minimum power—h.p.$_{ro}$).

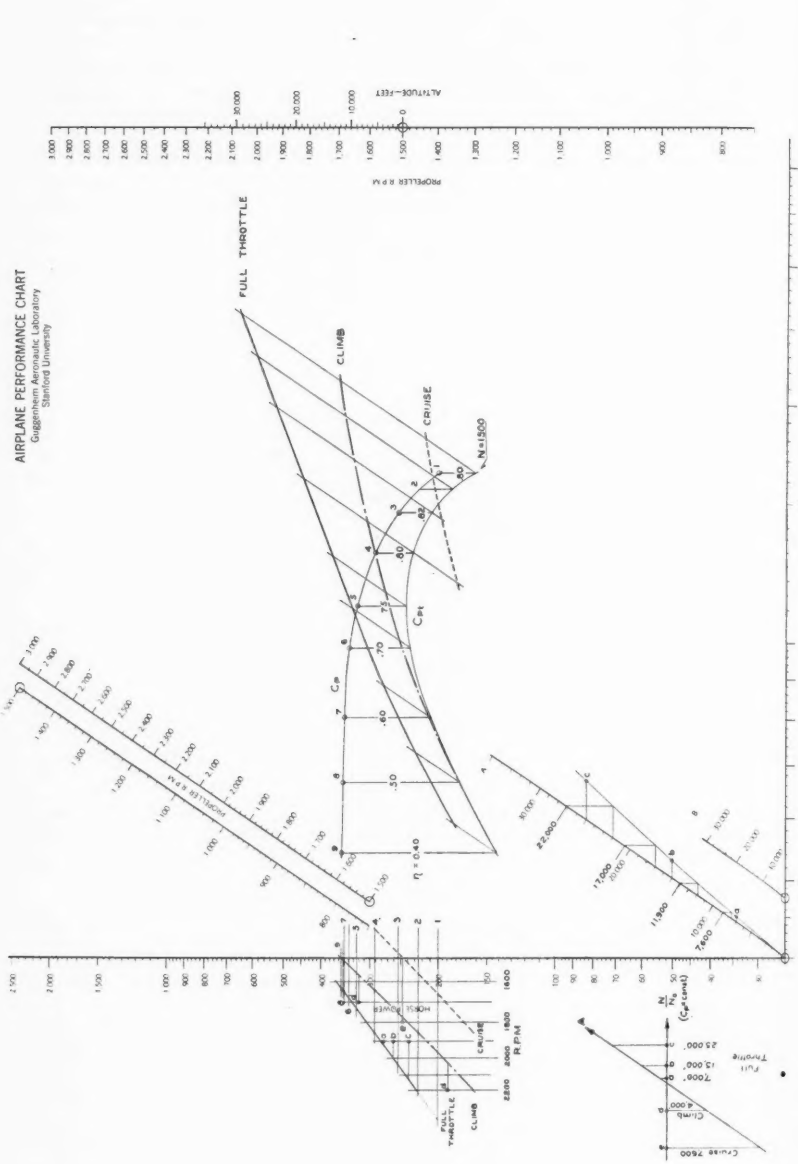

FIG. 7.—*Fixed pitch propeller.*

engine operating condition. The auxiliary displacement curve (*abc*[7]), alongside scale *A*, serves this purpose for the full throttle condition; the "*x* component" of the additional displacement for any altitude is the horizontal distance from the corresponding point of scale *A* to the auxiliary curve. The positions of the reference point[8] of the tracing sheet for altitudes of 7,600, 11,900, 17,000 and 22,000 ft. are identified by the auxiliary height figures distributed along scale A.

Since the top speed and maximum rate of climb of an aeroplane which has a fixed pitch propeller vary almost linearly with height when a constant intake manifold pressure is maintained it will usually suffice to determine the performance

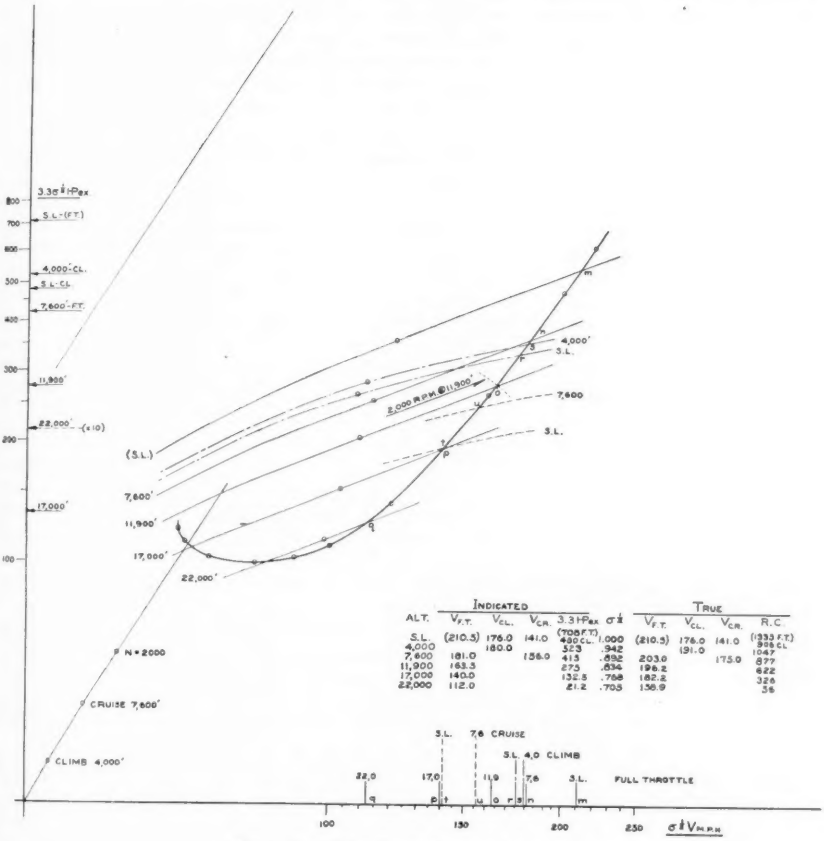

FIG. 8. *Fixed pitch propeller.*

attainable under the climb and cruising power limits at only one altitude in addition to sea-level.[9] In the present example, engine characteristics indicate the

[7] Construction: Plot values of b.h.p./σ versus N for three well-spaced altitudes and some convenient r.p.m., *e.g.*, a—7,000′, b—15,000′, c—25,000′—all at 1,900 r.p.m. in this case. From same altitudes on scale A, lay off the horizontal distances of a, b and c from the full-throttle power curve.

[8] Intersection of h.p. and V axes, *i.e.*, point 3 of Fig. 4.

[9] See Fig. 9; intersections of part- and full-throttle rev. curves are fixed by engine characteristics, *i.e.*, "F.-T. r.p.m. Limits" are curves of altitude vs. full-throttle r.p.m. at constant i.m.p.

desirability of evaluating " climb " performance at 4,000 ft. and cruising speed at 7,600 ft.

Two points designated " d " will be found between the climb and full-throttle engine power curves of Fig. 7; they represent values of b.h.p./σ which correspond to the climb power limit (33 in. Hg.), at 4,000 ft. Since they are equally distant from the sea-level climb power curve, it is evident that the 4,000 ft. power curve is horizontally equi-distant from the sea-level one at all points and, therefore, that the 4,000 ft. curve of $\sigma^{1/2}$ t.h.p. versus $\sigma^{1/2}V$ will be simply a displaced replica of the corresponding sea-level curve.[10] The " additional displacement " (analogous to " A " in Fig. 4) is determined by the construction shown in the auxiliary diagram below the engine power curves of Fig. 7. The fact that its sense is opposite to that of the full throttle ones (also shown in the auxiliary diagram) is accounted for by the continuous *increase* of b.h.p./σ with altitude which occurs when intake manifold pressure and r.p.m. have fixed values.

Only one point " e," is used to determine the " additional displacement " in the case of the cruising power curve for 7,600 ft. altitude. Since the rate of climb is not to be evaluated under this condition, the location of only that segment of the available power curve adjacent to its intersection with the required curve need be accurately determined. In this case, inspection of the required power curve (see next paragraph) reveals that the intersection will occur between the points of the available curve which are defined by the construction lines connected with points 2 and 3 of the C_p curve. Therefore, to correctly determine the " additional displacement " of this segment, the definitive horizontal distance (analogous to x—Fig. 4) should be measured along a horizontal line located between points 2 and 3 of the C_p curve. Thus the 1,800 r.p.m. value of b.h.p./σ for 7,600 ft. is found to satisfy this requirement, *i.e.*, point " e " is between the horizontals through points 2 and 3. The construction which determines the " additional displacement " is also shown in the auxiliary diagram of Fig. 7.

Fig. 8 is the tracing made from Fig. 7. In preparing it, the curve of $\sigma^{1/2}$ t.h.p.$_r$ versus $\sigma^{1/2}V$ (identical with t.h.p.$_r$ versus V, at sea-level) is plotted first. The three sea-level curves of $\sigma^{1/2}$ t.h.p.$_a$ versus $\sigma^{1/2}V$ (full-throttle, climb and cruise) are then traced. The full-throttle curves of power available at altitude are drawn by displacing the reference point of the tracing to each of the previously identified points of the A scale and tracing the sea-level full-throttle curve in each of these positions. To draw the 4,000 ft. curve of $\sigma^{1/2}$ t.h.p.$_a$ under the climbing power limitation, the displacement corresponding to point " d " (Fig. 7) is laid off in reverse direction from the reference point of the tracing; it is designated " climb 4,000 ft." Shifting the tracing sheet to bring this point into coincidence with the 4,000 ft. division of scale A, the sea-level " climb " curve is then traced. A similar procedure is followed in the case of the cruising power curve for 7,600 ft. altitude; the displacement defined by point " e " is identified on the tracing by " cruise 7,600 ft."

The intersections of the available and required power curves are projected vertically to the velocity scale and the values of these indicated air speeds are tabulated. Use of the transparent " climb chart " enables the determination of 3.3 $\sigma^{1/2}$ t.h.p.$_{ex}$ for each altitude and power condition; these values are identified by arrows which point to the h.p. scale and are also listed in the table. The true air speeds of level flight are obtained by dividing the indicated ones by appropriate values of $\sigma^{1/2}$; the rates of climb are calculated by dividing 3.3 $\sigma^{1/2}$ h.p.$_{ex}$ by $\sigma^{1/2}$ W/10,000.

The accuracy of the new method is graphically illustrated by Fig. 9 where the results tabulated on Fig. 8 are compared with those obtained from the same basic data by use of the laborious, but highly accurate, modified Bairstow method. (Reference 5.)

[10] This is not always true of the climb power curves; see Appendix for methods applicable to such cases.

The curve designated " 2,000 r.p.m. at 11,900 ft." (Fig. 8) demonstrates satisfaction of the propeller design conditions. This curve has no relation to the engine characteristics; it is a fictitious one of $\sigma^{1/2}$ t.h.p.$_a$ versus $\sigma^{1/2}V$ *at constant r.p.m.* and was constructed by appropriate displacement of the C_{Pt} curve. (Trace C_{Pt} with tracing shifted to place " $N=2{,}000$ " point—Fig. 8—upon 11,900 ft. division of Fig. 7's scale *A*.) As the propeller diameter and pitch were selected to hold the r.p.m. to 2,000 in full-throttle level flight at 11,900 ft. altitude, the proximity of the fictitious curve to the intersection of the available and required ones for this altitude indicates the accuracy of the choice.

In contrast with most methods of performance prediction, the determination of the r.p.m. which correspond to an arbitrary condition of flight is readily accomplished by use of Figs. 7 and 8. For example, to evaluate the r.p.m. for full-throttle level flight at 22,000 ft., the reference point of the tracing is shifted to the 22,000 ft. point of Fig. 7's Scale *A*. One then measures, along the direc-

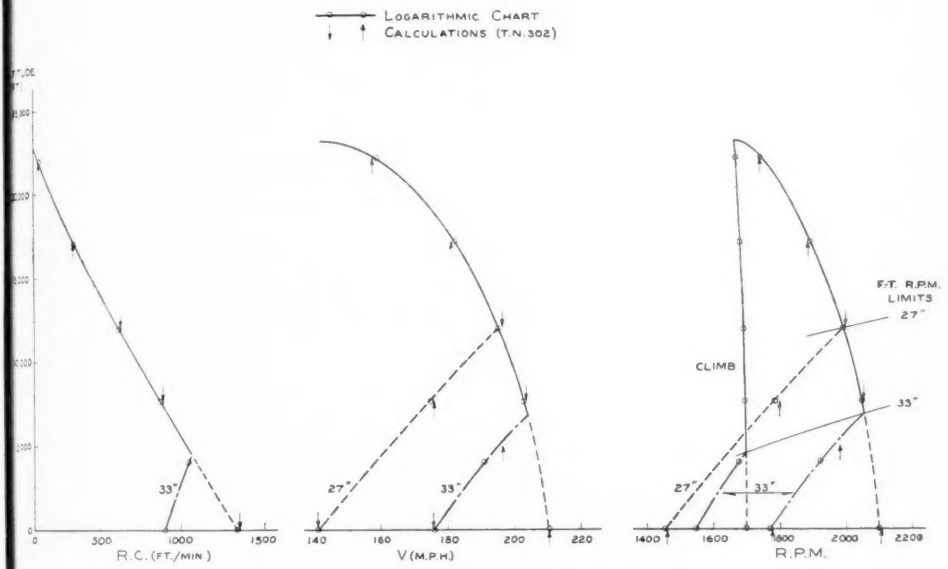

FIG. 9.

tion of the r.p.m. axis, the distance *from* the C_{Ft} curve *to* the point q of the 22,000 ft. available power curve. Stepping off this distance in the same direction from the reference point of the N scale yields the desired result, 1,745 r.p.m.

II. CONSTANT SPEED PROPELLER.

A new type of propeller characteristic chart furnishes the key to a surprisingly simple method of predicting the performance of aeroplanes equipped with constant speed propellers. To follow the development of this chart, one has only to recognise the fact that, when such a propeller is operated at fixed values of r.p.m. and b.h.p. input, the variation of blade angle with air speed is that required to maintain the power coefficient ($C_P=550$ b.h.p./ρn^3D^5) at a constant value.

The curves of Fig. 2 are reproduced in Fig. 10. Upon this chart, a horizontal line has been drawn at the ordinate $C_P=0.05$. It will be seen that the power coefficient 0.05 is attained at a V/nD of about 0.31 with a 20° blade setting,

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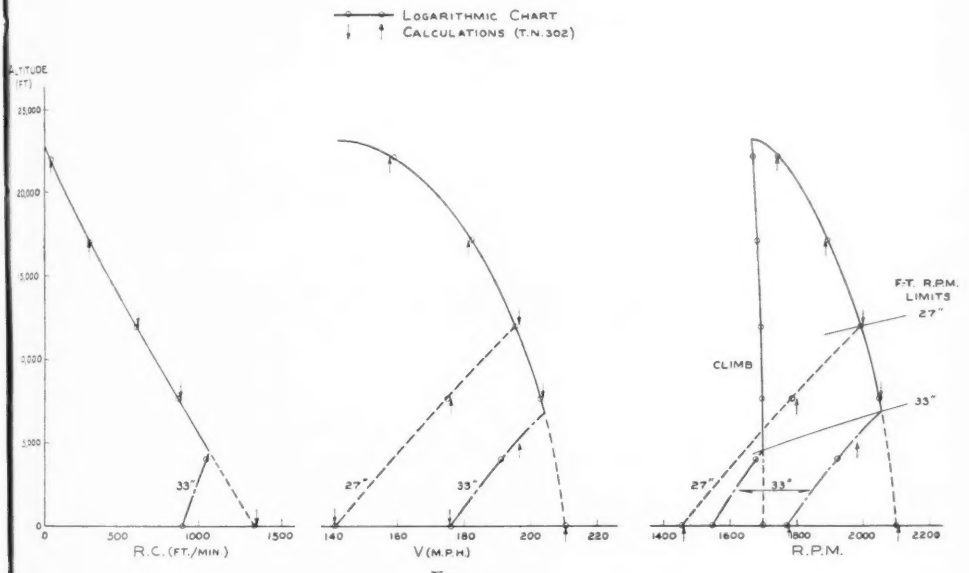

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The curves of Fig. 2 are reproduced in Fig. 10. Upon this chart, a horizontal line has been drawn at the ordinate $C_P=0.05$. It will be seen that the power coefficient 0.05 is attained at a V/nD of about 0.31 with a 20° blade setting,

at 0.62 with 22°, at 0.80 with 24°, and so on. Since the value of the efficiency is known for each of these conditions, the corresponding values of the thrust power coefficient ($C_{Pt}=\eta C_P$) can be determined. By this method, or the more convenient one of Fig. 10 which utilises the efficiency contours, it is possible to determine *a curve of C_{Pt} versus V/nD which represents the thrust power characteristics of a constant speed propeller when operated at a given value of C_P.* The curves of

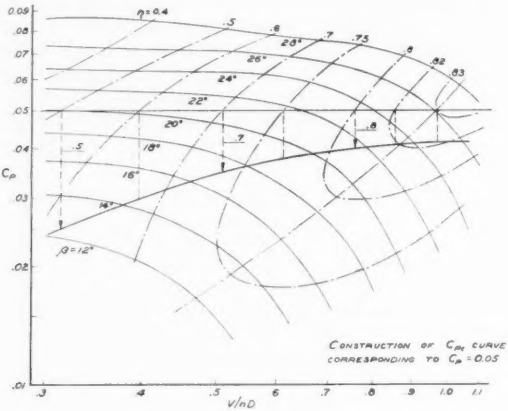


FIG. 10.

Fig. 11 have been derived from those of Fig. 2 by this method; auxiliary divisions have been added to facilitate interpolation and two typical blade angle contours are shown.

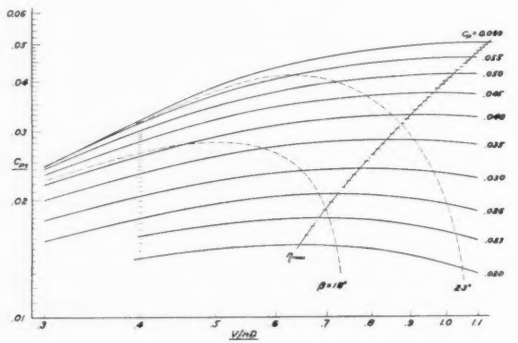


FIG. 11.

It will now be apparent that proper superposition of Fig. 11 upon the Performance Chart and knowledge of the value of C_P for some particular condition of engine operation is sufficient to enable the construction of the corresponding curve of $\sigma^{1/2}$ t.h.p.$_s$ versus $\sigma^{1/2}$ V because the properties of the Eiffel chart which have been utilised in dealing with fixed pitch propellers are equally applicable to manipulation of the t.h.p. versus V curves for constant speed propellers. Thus, such curves are displaced upwardly and toward the right with increasing r.p.m., downwardly with increasing altitude and downwardly and toward the left by the transposition from " true " to " indicated " co-ordinates.

These relationships are illustrated by Fig. 12. The locations of the axes of Fig. 11 (determined by equations (1) and (2)) are shown by the dashed lines and skeletonised scale designations. The vertical scales at the right side of the Performance Chart are used for graphical determination of the value of C_P. In the example, a direct-drive engine is assumed to produce 389 b.h.p. at 2,000 r.p.m. at 17,000 ft. altitude; the construction (laying off Y from b.h.p.) fixes the value of C_P at 0.04. The C_{Pt} curve which corresponds to $C_P = 0.04$ is designated

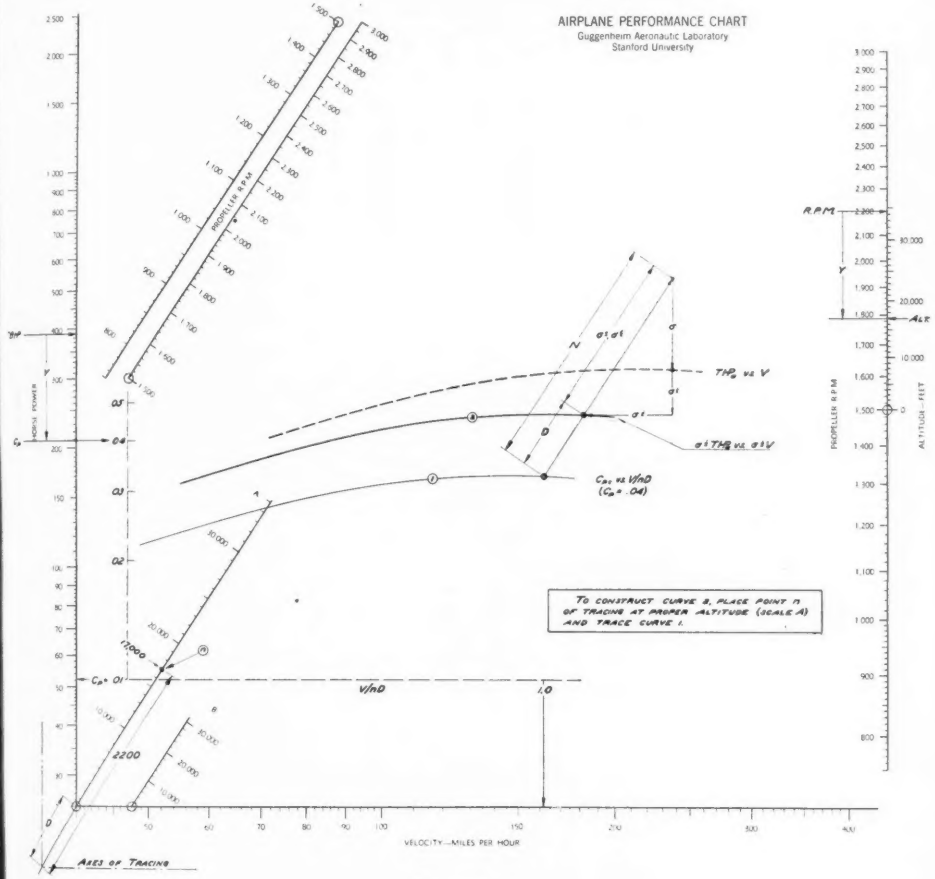


FIG. 12.

1; in accordance with the properties illustrated by Fig. 1, the broken line curve "t.h.p.$_a$ versus V" is derived from 1 by displacements appropriate to the r.p.m. (2,200) and air density (0.589). The displacements required to transform this curve into one of $\sigma^{1/2}$ t.h.p.$_a$ versus $\sigma^{1/2}$ V (Curve 2) are similar to those previously illustrated in Fig. 4. The method of locating the tracing sheet so that the 17,000 ft. available power curve may be drawn by tracing the sea-level C_{Pt} curve (1) is also shown on Fig. 12. *This displacement scheme is equally applicable to the construction of all the available power curves involved in a constant-speed propeller prediction.* However, attention is called to the fact that

all of these curves are not tracings of the same C_{Pt} curve; the curve which is to be traced is identified by the particular value of C_P which corresponds to the values of σ, N and b.h.p. for the operating condition involved.

EXAMPLE.

Fig. 13 is a photograph of the Performance Chart used to predict the characteristics of the same aeroplane which was used in the previous example; in this

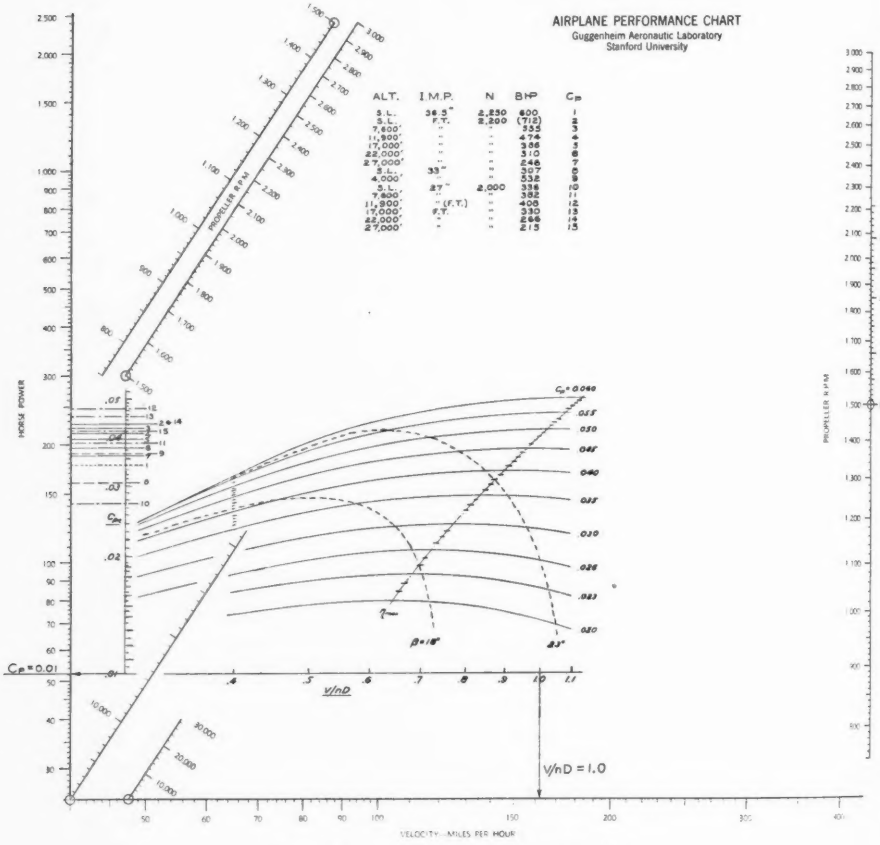


FIG. 13. *Constant speed propeller.*

case, it is assumed to be equipped with a constant speed propeller whose blades are identical with those previously used in the adjustable hub. It will be seen that a print of the curves of Fig. 11 has been fastened upon the chart and cut away to expose the scales. The altitudes and engine operating conditions for which available power curves are to be constructed are tabulated and each group of data is given a number (under heading C_P) so that the short horizontal lines which define the corresponding values of C_P may be readily identified.

The tracing made by use of this chart is shown in Fig. 14. Since operation is confined to three values of r.p.m., only three reference points need be located

on the line which matches scale *A* of Fig. 13. The air speeds of level flight and the rates of climb are evaluated exactly as described in connection with the fixed pitch example.

The results obtained from Fig. 14 are shown in Fig. 15; the curves for the fixed pitch example are also reproduced there for convenience of comparison. It is interesting to notice that although there is a negligible difference between the cruising speeds at the optimum altitude (approx. 12,000 ft.), the constant speed propeller enables the attainment of increased cruising speeds at all other altitudes as well as greatly improving the climbing performance.

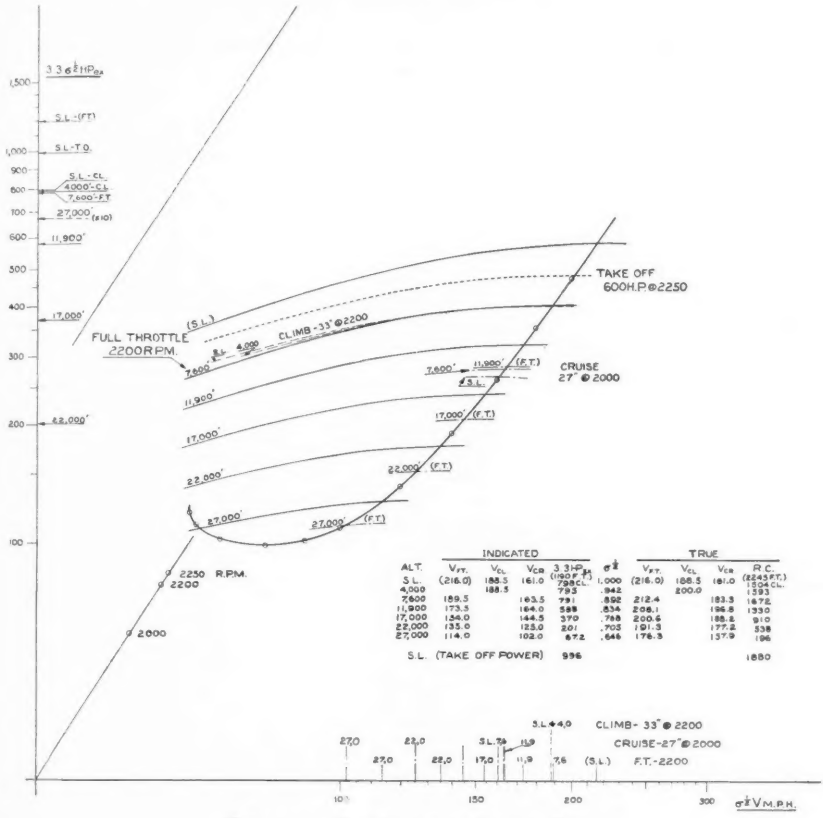


FIG. 14. *Constant speed propeller.*

CONCLUDING REMARKS.

The description of this new method of prediction has been illustrated by examples involving only a single-engine aeroplane of moderate power. Lest it be thought that special charts must be prepared to accommodate very powerful engines or multi-engine aircraft, it is pointed out that the horse-power scale may be modified indefinitely by multiplying its designations by any power of 10 and that multi-engine problems may be conveniently treated by dealing with the available and required power on a " per engine " basis.

While it is true that use of the new method involves a certain " load of fixed equipment," *i.e.*, printed blanks, a " climb chart " and special propeller curves,

limited experience is sufficient to prove that it does enable the making of rigorous performance predictions without the drudgery to which we have unwillingly become accustomed.

APPENDIX.

Critical examination of Fig. 4 reveals that the validity of the " displacement tracing " method of constructing altitude power available curves depends upon the constancy of the horizontal distance between the sea-level and altitude curves of b.h.p./σ versus N. Therefore, the method is rigorously correct *only* when the engine power curves involved are horizontally equi-distant throughout their lengths.

Since the variation of air density causes the full-throttle power output of an

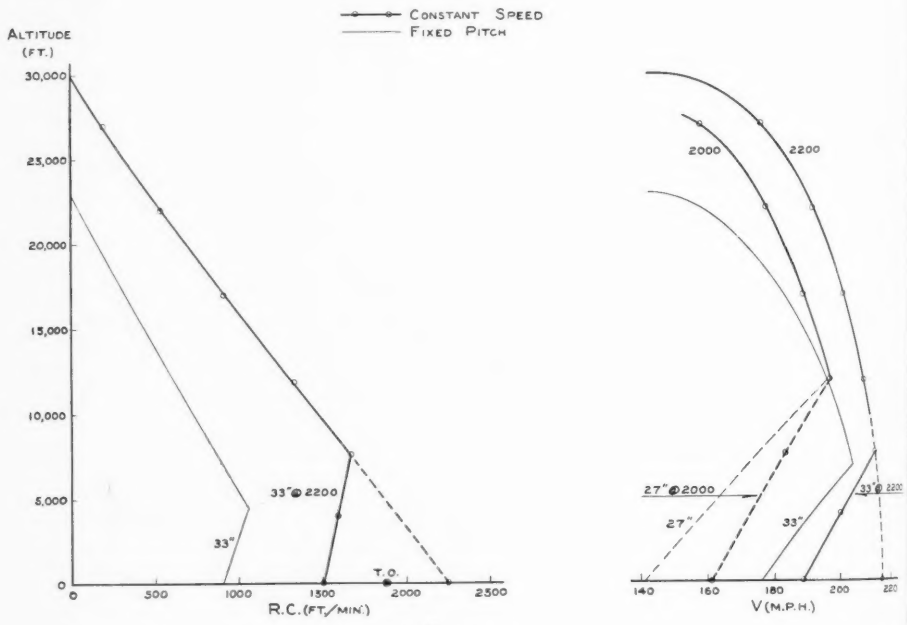


FIG. 15.

engine to be altered by the same percentage at all speeds, the altitude full-throttle curves of b.h.p./σ versus N for all engines[11] are vertically displaced replicas of the corresponding sea-level curves. Fig. 16 shows that the sea-level full-throttle curves for modern engines depart negligibly from rectilinear form when plotted in logarithmic co-ordinates. Therefore, uniform horizontal, as well as vertical, separation exists under these conditions and the displacement tracing method yields correct results *under the conditions of full-throttle operation.*

In the case of an engine operating at constant in-take manifold pressure, one might expect the curves of b.h.p./σ versus N to approximate the rectilinear form which characterises constant torque, *i.e.*, the 45° broken line of Fig. 16. While this is true of engines which are supercharged moderately or not at all, the curves for highly supercharged engines cannot be so described. Fig. 17 illustrates the rather extreme case of an engine which has a 15,000 ft. critical altitude.

[11] With possible exception of those incorporating turbo-superchargers.

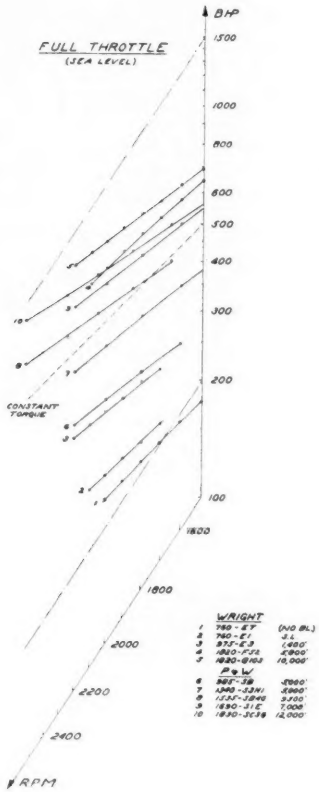

BHP
FULL THROTTLE
(SEA LEVEL)
1500
1000
800
600
500
400
300
200
100
CONSTANT TORQUE
1800
2000
2200
2400
RPM
WRIGHT
P&W

FIG. 16.

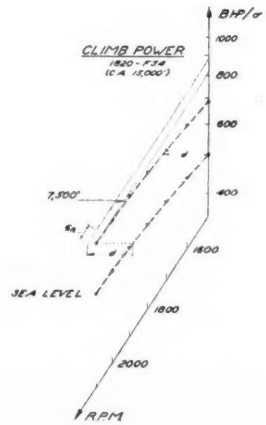

BHP/σ
CLIMB POWER
1000
800
600
400
7,500'
SEA LEVEL
1800
2000
RPM

FIG. 17.

The non-uniformity of the separation of the sea-level and 7,500 ft. " climb " power curves is evident and one sees that use of the displacement tracing method might involve an error as great as ϵ_n if the " additional displacement " were defined by the distance d. Under such conditions, it is obvious that if accurate results are to be obtained one or two additional curves of $\sigma^{1/2}$ t.h.p.$_a$ versus $\sigma^{1/2}$ V—for altitudes below the critical one—will have to be constructed. However, this may be readily accomplished by shifting the tracing through the distance which would correspond to d and then drawing the distorted curve determined by applying corrections similar to ϵ_n at a few points of the previously constructed sea-level t.h.p.$_a$ curve.

Although the non-uniformity of the horizontal distance between the sea-level and altitude engine power curves naturally becomes more pronounced as the intake manifold pressure limit is reduced from the " climb " to the " cruising " value, it has been pointed out that appropriate displacement enables accurate determination of the cruising speed at any altitude.

It thus appears that the previously outlined procedure is not at all seriously complicated even though the problem involves a highly supercharged engine.

References.

1. Eiffel, Gustave. Nouvelles recherches sur la resistance de l'air et l'aviation faites au Laboratoire d'Auteuil. Paris, H. Dunod et Pinat, 1914, page 309.
2. Durand, W. F. Experimental research on air propellers. N.A.C.A. Technical Report No. 14, 1917, Part II.
3. Weick, F. E. Aircraft propeller design. New York, McGraw Hill, 1930, page 97.
4. Schrenk, M. A few more mechanical-flight formulas without the aid of polar diagrams. N.A.C.A. Technical Memorandum No. 457, 1928.
5. Lesley, E. P., and Elliott G. Reid. A new method for the prediction of airplane performance. N.A.C.A. Technical Note No. 302, 1929.
6. Bilbault, G. Utilisation pratique de la polaire logarithmic pour le calcule des performances des avions. Paris, F.-L. Vivien, 1930.

ABSTRACTS FROM THE SCIENTIFIC AND TECHNICAL PRESS.

Issued by the

Directorates of Scientific Research and Technical Development, Air Ministry.

(Prepared by R.T.P.)

No. 74. JANUARY, 1940.

Defence Against Dive Bombing Attacks. (B. di San Secondo, Rivista Maritima, Dec., 1938. Luftwehr, Vol. 6, No. 3, March, 1939, pp. 121-124.) (74/1 Italy.)

Dive bombing attack can be divided into five phases:—

(1) Spiral from 10,000 m. distance to 2,000 m., with gradual loss of height from 5,000 m. to 1,500 m.
Time taken 90 secs., if speed is assumed at 120 m./sec.

(2) Horizontal speed reduced to 40 m./sec. whilst getting into position for attack. The course during this phase is usually at 30—40° with the direction of the dive (10 seconds).

(3) Actual dive at about 70° on to target (7 seconds).
Target distance at beginning of dive ~ 1,500 m.
Target distance at end of dive ~ 600 m.

(4) Release of bomb and pull out (2 seconds).

(5) Spiral get away with gradual climb (90 seconds).

During phases (1) and (5) the attacking aircraft has complete manœuvrability and therefore is difficult to hit by A.A. fire. The sudden reduction in speed in phase (2) is also very disconcerting to the artillery. The chances of hitting the aircraft should be greatest during phase (3) when the flight path of the aircraft must necessarily almost coincide with the trajectory of the bullets. Phase (4) is too short to be considered from the point of view of the A.A. artillery. Unfortunately phase (3) is also very short (of the order of 7 seconds), and unless the explosive shells can be relied on to furnish high-speed fragments in sufficient quantity and in the direction of the aircraft, the effectiveness of the fire is very doubtful.

For this reason the author follows Rougeron and recommends the use of shrapnel, each 10 cm. shell containing about 240 bullets. The bullets are expelled inside a relatively small cone, and at a distance of 100 m. from the burst we may roughly expect one bullet per sq. m., whilst at 600 m. the proportion is one bullet per 39 sq. m.

Even should the bullets be met at an appreciable distance from the point of burst, the impact velocity due to the high speed of the aircraft will accentuate the damage.

Fighter versus Bomber—Italian Experiences in Spain. (Rev. de l'Arm. de l'Air, No. 116, May-June, 1939, pp. 313-319.) (74/2 Italy.)

An interesting discussion on this subject has been published in the Vie dell'Aria towards the end of 1938. The French reviewer calls attention to the value of

publications of this kind based on actual war experience, and points out that many of the early mistakes in the 1914 war could have been avoided if the experiences gained in the Balkan War of 1912 had been published instead of being pigeon-holed.

Main claims for the fighter (put forward by M. Fucini) :—

(1) Greater stability of gun mounting and therefore increased accuracy of fire.
(2) Advantage of fire and aircraft being under control of one man.
(3) Small vulnerable surface.
(4) Although difference in top speed and ceiling may not be very great between the two types of aircraft, the fighter can gain considerable speed by diving on its objective. The bomber is forced to fly low in order to obtain bombing accuracy.
(5) Mutual fire support is seriously interfered with by A.A. artillery, which will force the bomber formation to break up and this facilitates fighter attack.
(6) Vulnerability of bomber is generally recognised by the provision of fighter escorts whenever possible. This was the universal practice of the Government forces.

The case for the bomber (Bruno Montanari) :—

(1) Since the ceilings of the two types are comparable, there is little chance of fighter contact if the bomber operates at high altitude.
(2) Bombing accuracy does not necessarily suffer as altitude increases. The Italians are able to place sixty heavy bombs in a space of 100—200 m. from 6,500 m.
(3) Concentrated fire of S79 bombers prove very effective against attacks by Rata fighters. Heavier guns can be carried by the bomber and thus outrange the fighter.
(4) Co-operation between fighter and A.A. artillery when attacking bombers was not successful in Spain. Many fighters were shot down by their own ground artillery.
(5) Although the bomber has the bigger surface, the vital parts are more dispersed and this makes for safety.
(6) Unescorted bombers (S79) proved very successful against Barcelona.
If escorts are required, the bomber is being utilised for duties, such as participation in ground fighting, which would be better carried out by special machines.
(7) The rôle of the fighter is to obtain mastery of the air over certain restricted zones (defence of vital objectives) or at certain times for the purpose of army co-operation.
(8) The main purpose of an air force is, however, long-distance bombing, and it must be the object of the bomber to reach his target at all costs. If intercepted by fighters, losses will naturally arise, but they will be on both sides equally and should not prevent the bomber from carrying out his mission.

Some Italian and Russian Opinions on the Aerial War in Spain. (Rev. de l'Arm. de l'Air, No. 116, May and June, 1939, pp. 319-322.) (74/3 France.)

Some of the principal conclusions are given below :—

Italian.

(1) The Spanish aerodromes are very rough and generally devoid of buildings. The aircraft is kept in the open at a distance (camouflaged) and can generally only be detected from a low altitude. A.A. artillery has proved very effective against such a form of attack.
(2) The high landing speeds of modern fighters has led to numerous accidents.
(3) The increased flying speed of the modern bomber is proving a severe handicap to the attacking fighter.

(4) The most suitable targets for ground attack are troops in improvised defensive positions. Troops or mechanised units can only be rarely surprised when on the march unless the leadership makes mistakes.

(5) The Italian method of ground attack in chains has proved very effective. Usually six to nine aircraft participate and dive on to the objective in succession. The low altitude flight is carried out at very high speed and losses are surprisingly small (40 casualties in 587 attacks involving 3,554 aircraft over the period 1st January, 1938, to 31st April, 1938, covering the important engagements at Teruel and on the Ebro). Only small-calibre A.A. guns can be employed, and hits, if registered at all, are very rarely serious.

(6) The Italians employed Breda 65, C.R. 32 and RO 37 machines for work of this kind. The ideal ground attack machine has yet to be designed. It must be armoured and possess exceptional visibility for the pilot.

Some Russian Opinions.

(1) The Y Rata fighter is praised for its good manœuvrability and general fighting capacity. A serious fault is its low ceiling, which made contact with Italian fighters (patrolling habitually at 7,000—7,500 m.) very difficult.

(2) The effect of ground attack is moral rather than material. With existing types, such attacks can only be carried out if supported by fighters which assure a temporary command of the sky. If unsupported by fighters, such units (of the order of ten aircraft) fall an easy prey to the fighter. Only mass attacks (50—100 aircraft) have any chance of success.

(3) Effective co-operation between the troops and the aircraft carrying out ground attack in front of the line is very difficult. Without such co-operation, the attack loses most of its value.

(4) It is agreed that aircraft flying low at high speed have little to fear from A.A. fire. The ideal machine for ground attack is not yet available. The Russian author suggests that it should be a three-seater so as to obviate the need of fighter support. 500 kg. of bomb should be carried.

In conclusion, the French reviewer calls attention to the apparent failure of aircraft reconnaissance in predicting the imminence of large-scale offensives by the enemy. A classical example is Ebro attack, which apparently took Franco by surprise in spite of his superiority in long-range reconnaissance aircraft.

Factory Hands Required for the Equipment of a Modern Air Force. (D. Leonhardt, Luftwehr, Vol. 6, No. 7, July, 1939, pp. 280-281.) (74/4 Germany.)

According to the French expert Rougeron, the proportion of flying personnel, ground troops and workpeople required for maintaining an air force at a given size is in the ratio 1 : 4 : 12.5. Italian calculations, based on front-line strength only, give 1 : 5 : 33. The two sets are in reasonable agreement if the front-line strength is of the order of one-third of the total.

A more detailed examination of the problem shows, however, that the non-combatant strength in relation to the flying personnel is likely to exceed the proportions given above. Let us assume that the total strength of an air force amounts to 10,000 aircraft, of which 3,000 are front-line machines. The monthly losses to be expected amount to 50 per cent. for front line and 25 per cent. for the rest. This requires a yearly output of 40,000 aircraft, plus an estimated output of 60,000 engines. An all-metal fighter requires about 14-18,000 man-hours for completion, each engine (1,000 h.p.) 8-9,000 man-hours. Taking 2,700 hours as the work output per man per year, the yearly requirements in aircraft and engines amount to the employment of $40{,}000 \times 6 + 60{,}000 \times 3 = 420{,}000$ men. Aircraft accessories (at 33 per cent.) and engine accessories (at 66 per cent.) account for another 200,000 men. But even this grand total of over 600,000 does not show the full requirements, since labour spent on repairs and the necessary

development work has not been included, nor has an allowance been made for armament and equipment of the combatants, ground organisation and fuel supply. The author estimates the grand total labour requirements for maintaining an air force at 10,000 aircraft under war conditions as being well over one million men.

A Russian Pilot's Opinion on the German Fighter in Spain. With Some Reference to Italian and French Aircraft. (*From the Russian.*) Riv. Aeron., Vol. 15, No. 9, September, 1939, pp. 501-2.) (74/5 U.S.S.R.)

The German fighters generally operate in three groups, of which the first two attack in turn.

The third group is fitted with cannons and remains in reserve at a greater altitude. These machines will dive at great speed on any suitable target below them.

The German pilot is trained to make the most of sun and clouds, and the camouflage paint is adjusted to the type of country in which the operation takes place.

The great art in air fighting is to know the blind spot of the adversary. Junkers fuel tanks are vulnerable to incendiary bullets if the machine is attacked from the rear and above.

On the other hand, the Fiat 32 is more vulnerable to attack from below.

The French Multi-seat Potez 54 (liquid-cooled bomber) is so vulnerable that each machine had to be protected by half-a-dozen fighters.

World's Aircraft Production, with Special Reference to the U.S.A. (Inter. Avia., No. 687, 5/12/39, pp. 1-4.) (74/6 Switzerland.)

U.S.A.

The Wall Street Journal estimates the 1940 capacity of the American aviation industry at 674 million dollars. This figure is considered unduly optimistic, seeing that the total November, 1939 sales (a record for the year) amounted to less than twenty million dollars.

The present back log of the industry amounts to no less than 534 million dollars.

Germany.

The German aviation industry has become most reticent, and the monthly trade journal " Luftwehr " has ceased publication. The following points should, however, be noted:—

(1) Even prior to September, 1939, at least 300,000 persons were employed in the German aviation industry.
(2) Advertisements for extra staff and published figures concerning increase in capital of a number of firms clearly indicate further expansion.
(3) The possibilities of the Czechoslovak and Polish aircraft industries are bound to become utilised to the fullest extent.

Great Britain and France.

Production figures are not available, but it clearly indicates the intention of the Allies (and more especially of France) to look to America as a source of supply.

In view of the position of the American industry, and the large demands of the U.S. Army Air Corps, the Swiss reviewer is doubtful whether any considerable help can be expected from that quarter during 1940.

New Driving Band for Projectiles (to Replace Copper Ring). (La Technique Moderne, Vol. 31, No. 21-22, 15/11/39, p. 18.) (74/7 Germany.)

The band consists of a mixture of asbestos fibre, paper and cotton reinforced by metal wires.

A mixture of graphite, talc, rubber and resin is used as a filler, adhesion being assured by high compression.

German War Time Labour Regulation. (Inter. Avia., No. 689, 19/12/39, p. 9.) (74/8 Germany.)

Upon the outbreak of war some of the regulations protecting labour were necessarily relaxed, but these modifications are now speedily to be removed again. An order issued on December 12th re-enforces the regulations previously promulgated. The daily working time is not to exceed eight hours without special sanction unless, of course, war orders are involved, necessitating accelerated execution. Even in the latter cases the daily working hours must not exceed ten, and, in exceptional cases, twelve. Wages are increased by 25 per cent. for overtime work beginning with the eleventh working hour. It is unlawful to employ women and minors on night shifts. A new set of regulations covering labour in Germany will come into force on January 1st, 1940.

On the Deformation of Free Boundary Due to Line Vortices. (I. Imai, Aer. Res. Inst., Tokyo Rept., No. 183, Aug., 1939.) (74/9 Japan.)

In this paper a method is developed for dealing with the two-dimensional irrotational motion of an incompressible perfect fluid bounded by free surfaces as well as by rigid walls, in which a number of line vortices are placed. The method is illustrated by taking several cases of interest, for which approximate solutions have been known for some time. The exact formulæ are obtained, however, for the first time in the present paper. In particular, Riegels's problem (one rigid wall and free surface), which was also attacked by Schmieden, is solved in a simple and exact manner.

Pressure Distribution Investigation of an N.A.C.A. 0009 Aerofoil with a 50 per cent. Chord Plain Flap and Three Tabs. (W. G. Street and M. B. Ames, Jr., N.A.C.A. Tech. Note No. 734, Nov., 1939.) (74/10 U.S.A.)

Pressure-distribution tests of an N.A.C.A. 0009 aerofoil with a 50 per cent. chord plain flap and three plain tabs, having chords 10, 20 and 30 per cent. of the flap chord, were made in the N.A.C.A. 4 × 6-foot vertical tunnel. The tests supplied aerodynamic section data that may be applied to the design of horizontal and vertical tail surfaces.

The results are presented as resultant-pressure diagrams for the aerofoil with the flap and the 20 per cent. chord tab. Plots are also given of increments of normal-force and hinge-moment coefficients for the aerofoil, the flap, and the three tabs. The experimental results and values computed by analytical methods are in good agreement for small flap and tab deflections. The results of the tests indicated that the effectiveness of all three tab sizes in reducing flap hinge moments decreased with increasing flap deflection.

Pressure Distribution Measurements on a Tapered Wing with a Partial-Span Split Flap in Curved Flight. (T. Troller and F. Rokus, N.A.C.A. Tech. Note No. 735, Nov., 1939.) (74/11 U.S.A.)

Pressure-distribution tests were made on the 32-foot whirling arm of the Daniel Guggenheim Airship Institute of a tapered wing to determine the rolling and the yawing moments due to an angular velocity in yaw. The model was tested at 0° and 5° pitch; 0°, 5° and 10° yaw; and with split flaps covering 25, 50, 75 and 100 per cent. of the wing span and deflected 60°. The results are given in the form of load distributions and as calculated moment coefficients.

CONCLUSIONS.

1. The experimental rolling- and yawing-moment coefficients for a wing without flaps are in close agreement with the theoretical values.

2. For a wing with a full-span or a partial-span flap, the experimental rolling-moment coefficients are 10 to 15 per cent. smaller than the theoretical values.

3. The rolling-moment coefficients were little affected by angle of yaw within the range of $\pm 10°$ with a tendency to decrease as the model was yawed in the positive direction. The yawing-moment coefficients were little affected by the angle of yaw for flap lengths up to 50 per cent. of the span, but showed considerable change for the full-span flap with a tendency to increase as the model was yawed in the positive direction.

Wind Tunnel Investigation of N.A.C.A. 23012, 23021 and 23030 Aerofoils with Various Sizes of Split Flap. (C. J. Wenzinger and T. A. Harris, N.A.C.A. Tech. Report No. 668, 1939.) (74/12 U.S.A.)

An investigation has been made in the N.A.C.A. 7 × 10-foot wind tunnel of large-chord N.A.C.A. 23012, 23021 and 23030 aerofoils with split flaps 10, 20, 30 and 40 per cent. of the wing chord to determine the section aerodynamic characteristics of the aerofoils as affected by aerofoil thickness, flap chord and flap deflection. The complete section aerodynamic characteristics of all the combinations tested are given in the form of graphs of lift, drag and pitching-moment coefficients, and certain applications to aerodynamic design are discussed.

The final maximum lift coefficients for the three aerofoils tested with the 0.20 cw. flap were about equal. For the aerofoils with the 0.10 cw. flap, the maximum lift coefficient decreased with aerofoil thickness; for the aerofoils with the 0.30 cw. or 0.40 cw. flaps, the maximum lift coefficient increased with aerofoil thickness to a maximum value of 2.94. Within the range covered, the increment of maximum lift coefficient due to the split flaps was practically independent of Reynolds Number. The increase in minimum profile-drag coefficient with aerofoil thickness was large, being about twice as great for the N.A.C.A. 23030 as for the 23012 plain aerofoil.

A Theoretical Study of the Moment on a Body in a Compressible Fluid. (C. Kaplan, N.A.C.A. Tech. Report No. 671, 1939.) (74/13 U.S.A.)

The extension to a compressible fluid of Lagally's theorem on the moment on a body in an incompressible fluid and Paggi's method of treating the flow of compressible fluids are employed for the determination of the effect of compressibility on the moment on an arbitrary body. Only the case of the two-dimensional subsonic flow of an ideal compressible fluid is considered. As examples of the application of the general theory, two well-known systems of profiles are treated, namely, the elliptic profile and the symmetrical Joukowski profiles with sharp trailing edges. The effect of compressibility on the position of the centre of pressure is also discussed. In order to determine this effect, it is necessary to calculate the additional circulation induced by the compressibility of the fluid for both the elliptic and the Joukowski profiles. For these two types of profile, the centres of pressure in the compressible and the incompressible fluids are found to coincide for a definite and fairly small angle of attack, which is essentially dependent on the thickness coefficients. For angles of attack less than this neutral angle, the centre of pressure in the compressible fluid is farther from the nose and, for angles of attack greater than the neutral angle, nearer to the nose than the centre of pressure in the incompressible fluid.

Several numerical examples of both the elliptic and the Joukowski profiles are given. The results show that, although the effect of compressibility on the moment and on the lift may be large, the effect on the centre of pressure for conventional profiles is negligible.

The Analogy Between Fluid Friction and Heat Transfer. (Th. von Kármán, Trans. A.S.M.E., Vol. 61, No. 8, November, 1939, pp. 705-710.) (74/14 U.S.A.)

The results of the modern turbulence research on velocity distribution near solid walls are applied to extend Reynolds' analogy between fluid friction and heat transfer to liquids. Discrepancies between the experimental results and the theory of Taylor and Prandtl are explained. A new theoretical formula which fits the experimental results more satisfactorily is suggested and compared with the empirical equations of Dittus and Boelter.

It appears from the results of this paper that the fundamental idea of Reynolds' analogy can be applied with success to the problem of friction and heat transfer between fluid and solid. However, it must be mentioned that recent experiments make it doubtful whether the same idea is applicable to exchange phenomena between fluids flowing with different velocities. It seems that in this case the exchange of heat occurs at a relatively higher rate than the exchange of momentum. At the present time the number of experiments is still too small to draw final conclusions. It is believed that the exchange mechanism of friction and heat transfer for the case " fluid versus fluid " is one of the most important topics for future research.

Wind Tunnel Investigation of an N.A.C.A. 23021 *Aerofoil with Various Arrangements of Slotted Flaps.* (C. J. Wenzinger and T. A. Harris, N.A.C.A. Report 664, 1939.) (74/15 U.S.A.)

The tests were carried out in the 7 × 10-foot wind tunnel and in the variable-density tunnel of the N.A.C.A.

1. The optimum arrangement of the slotted flap tested was superior to the split, the plain, and the external aerofoil types of flap compared on the basis of maximum lift coefficient, low drag at moderate and at high lift coefficients, and high drag at high lift coefficients. The slotted flap, however, gave slightly lower maximum lift coefficients than the Fowler flap.

2. The increment of maxium lift due to the slotted flap was found to be practically independent of the Reynolds Number over the range investigated.

3. Openings in the lower surface of the aerofoil for the slotted flaps tested had a measurable effect on the drag for high-speed flight conditions even when the slot was smoothly faired to maintain the contour of the upper surface and there was no air flow through the slot.

4. The slotted flap gave the highest maximum lift coefficients when the nose of the flap was located slightly ahead of, and below, the slot lip, and with a slot lip that directed the air down over the flap.

5. The lowest profile drags at moderate lift coefficients were obtained by using a slotted flap with an aerofoil nose shape and with an easy entrance to the slot.

6. It appears that still further improvement may be obtained in low drag characteristics at moderate and high lift coefficients by the use of multiple flaps or by slotted flaps with greater lip extensions.

Free-Spinning Wind Tunnel Tests of a Low Wing Monoplane with Systematic Changes in Wings and Tails. IV. Effect of Centre of Gravity Location. (O. Seidman and A. I. Neihouse, N.A.C.A. Report No. 672, 1939.) (74/16 U.S.A.)

The tests were carried out in the N.A.C.A. free spinning tunnel.

By analysis of the data presented, the following conclusions may be obtained:—

Effects of centre-of-gravity location:—

1 In nearly every case, moving the centre of gravity forward steepens the

spin, increases $\Omega b/2V$ and improves recovery; whereas moving the centre of gravity back flattens the spin, decreases $\Omega b/2V$, and retards recovery.*

2. Forward movement of the centre-of-gravity position tends to produce more outward sideslip, except for the wing of N.A.C.A. 6718 section, for which the reverse is true.

Effects of wings:—

1. Tip shape.—Rectangular and faired tips give the steepest spins and the most rapid recoveries. The Army tip consistently gives flatter spins and slower recoveries.

2. Plan form.—The wing of 5: 2 taper generally gives slower recoveries than the rectangular wing.

3. Section.—The N.A.C.A. 23012 section consistently exhibits the poorest recovery characteristics. The N.A.C.A. 0009 section gives the most outward sideslip; whereas the N.A.C.A. 6718 section gives inward sideslip.

Wind Tunnel Investigation of an N.A.C.A. 23021 Aerofoil with Various Arrangements of Slotted Flaps. (C. J. Wenzinger and T. A. Harris, N.A.C.A. Report No. 677, 1939.) (74/17 U.S.A.)

An investigation has been made in the N.A.C.A. 7 × 10-foot wind tunnel of a large-chord N.A.C.A. 23021 aerofoil with several arrangements of 25.66 per cent. chord slotted flaps to determine the section aerodynamic characteristics as affected by slot shape, flap shape, flap location and flap deflection. The flap positions for maximum lift, the polars for arrangements considered favourable for take-off and climb, and the complete section aerodynamic characteristics for selected optimum arrangements were determined. A discussion is given of the relative merits of the various arrangements for certain selected criteria. A comparison is made of a slotted flap on the N.A.C.A. 23021 aerofoil with a corresponding slotted flap previously developed for the N.A.C.A. 23012 aerofoil.

The best slotted-flap arrangement on the N.A.C.A. 23021 aerofoil gave the same maximum lift coefficient as the best slotted flap on the N.A.C.A. 23012 aerofoil. The drag coefficients were higher with the N.A.C.A. 23021 aerofoil, but the pitching-moment coefficients were about equal for comparable arrangements.

Wind Tunnel Investigaion of an N.A.C.A. 23012 Aerofoil with a Slotted Flap and Three Types of Auxiliary Flap. (C. J. Wenzinger and W. E. Gauvain, N.A.C.A. Report No. 679, 1939.) (74/18 U.S.A.)

An investigation was made in the N.A.C.A. 7 × 10-foot wind tunnel to determine the aerodynamic section characteristics of an N.A.C.A. 23012 aerofoil with a single main slotted flap equipped successively with auxiliary flaps of the plain, split and slotted types. A test installation was used in which an aerofoil of 7-foot span was mounted vertically between the upper and the lower sides of the closed test section so that two-dimensional flow was approximated.

On the basis of maximum lift coefficient, low drag at moderate and high lift coefficients, and high drag at high lift coefficients, the optimum combination of the arrangements was found to be the double-slotted flap. All the auxiliary flaps tested, however, increased the magnitudes of the pitching moments over those of the main slotted flap alone.

Study of Some Technical Problems Relating to the Wing Theory. Application of the Rheo-Electric Method to Their Solution. (L. Malavard, Pub. Sci. et Tech., No. 153, 1939.) (74/19 France.)

The rheo-electric method of analogy for solution of hydro- and aerodynamic

* $\Omega b/2V$ = spin coefficient where
Ω = resultant angular velocity,
b = span of wing,
V = rate of descent.

problems was described in Pub. Sci. et Tech., No. 57, 1934; it consists in producing electric currents distributed in conductors of two or three dimensions and giving a reproduction of the fluid flow. The method is now applied to the study of lifting wing problems, and an electrical apparatus has been developed known as the "wing calculator." It is applied to calculation of wings, in particular the effect of ailerons, and determination of the effect of the boundaries of the jet in wind tunnels. The solutions obtained are quite general and can be used for jets of any cross-section.

The two final chapters deal with the general problem of the biplane, an entirely new application of the calculator being made to the study of a biplane of finite span. The conditions which define in the electrical device the free vortices of a multiplane cellule do not reduce to the same form as in the case of a monoplane, so that the "multiplane wing calculator" employed has been considerably modified.

[See also Translation No. 837, L. Malavard, "The Application of Electrical Analogies to Some Aerodynamic Problems," E.N.S.A., No. 1, Jan.-Feb., 1937, pp. 62-73; No. 2, Mar.-Apr., 1937, pp. 5-12; No. 7, Jan.-Feb., 1938, pp. 39-50.]

U.S.A. Aircraft Year Book, 1939. (Inter. Avia., No. 686, 27/11/39, p. 17.) (74/20 U.S.A.)

An average of 36,000 employees were hired by the manufacturers of planes and engines in 1938; their export trade gave employment to about 15,000 shop employees, and 44 cents of the average sales dollar was paid to shop labour. The average shop employee in the aeroplane plants received an annual wage of $1,550. A comparatively small figure is given as the expenditure by the National Advisory Committee for Aeronautics: $6,002,480 for the five fiscal years 1935-1939; in approximately the same period of time, during the calendar years 1934-1938, the aeroplane, aeroplane engine and propeller manufacturers of the United States spent $44,000,000 on research and development work to improve American flying machines. During this same period, exports of American flying equipment amounted to $143,000,000, while commercial sales inside the United States aggregated $107,000,000; therefore, commercial, domestic and export sales amounted to $250,000,000. At the beginning of 1939 there were 11,744 non-military aircraft in the United States, 208 gliders, 24,443 aeroplane pilots, 116 licensd glider pilots, 2,374 landing fields of all kinds, 719 of the latter either fully or partially lighted for night flying.

A New Method of Assisted Take-off for Aircraft. (La Technique Moderne, Vol. 31, No. 21-22, 15/11/39, p. 18.) (74/21 France.)

The aircraft is towed by means of a tractor and cable. The cable passes over a special system of pulleys carried on a trailer placed between tractor and aircraft. At the beginning of the run both tractor and trailer advance at the same speed. The trailer is then deceleratd (braked), the tractor continuing to advance. This causes a rapid acceleration of the aircraft due to the pulley system which the rope has to pass.

Analysis of Best Rate of Climb and Ceiling as Affected by Ice Accretions. (A. Gail, J. Aeron. Sci., Vol. 7, No. 1, Nov., 1939, pp. 6-11.) (74/22 U.S.A.)

The polarless performance analysis is extended for non-parabolic polars which are characteristic of aerofoils with surface irregularities such as ice accretions. Oswald's aeroplane efficiency factor is interpreted in terms of "pseudo aspect ratio." The condition of maximum rate of climb is analytically defined and its iterative determination is demonstrated for the case of a given non-parabolic polar.

Impairments of best climb due to ice as experienced in flight can, with reasonable accuracy, be considered as a function of the " pseudo aspect ratio " only.

Conclusions.

By means of the above theory it is possible to establish the relationship between size, shape and location of ice accretion and a generally applicable aerodynamic parameter depending upon the flight or wind-tunnel test results available for analysis. Once this parameter is obtained for the most important ice formations, it will be possible to predict whether or not an aeroplane will be able to maintain flight above a certain altitude under certain anticipated icing conditions. Furthermore, the merits of various anti-icing means can be rated in terms of their effectiveness in preserving climbing ability and ceiling, thus permitting a more rational development of such anti-icing equipment.

No consideration has been given to propeller icing. Very little is known about the effect of surface irregularities upon propeller efficiency and about the shape of ice accretions on propellers. Hence, analyses of climb impairments with ice on the propeller have to be taken with reservations. The influence of propeller ice on performance is, however, small, since only deposition on the shanks is possible.

Reduction of Flight Test Climb Data to Standard Air Conditions. (R. J. White, J. Aeron. Sci., Vol. 7, No. 1, Nov., 1939, pp. 12-17.) (74/23 U.S.A.)

General equations for the reduction of flight test climb data to standard air conditions are given, indicating how the aeroplane and engine characteristics affect the necessary rate of climb corrections. Charts are given to provide an aid in the reduction of climb data of aeroplanes having modern engine installations.

The method of climb reduction presented is then expressed in terms of the " equivalent climb altitude," which has had wide use in the past. The author feels that this correlation shows the limitation of each method, and when one or the other is best suited. The equivalent climb altitude constant K is shown to depend mainly upon Oswald's aeroplane parameter, which enables K to be readily selected for almost any type of aeroplane. While $K \cong 0.37$ for modern bimotor aeroplanes in two-engine climb, it may increase to $K \cong 0.50$ for the same aeroplane in single-engine flight.

Means for Suppression of Interference Burble. (P. E. Hovgard, J. Aeron. Sci., Vol. 7, No. 1, Nov., 1939, pp. 22-25.) (74/24 U.S.A.)

Low-wing monoplanes using radial engines have been in use long enough so that the manner of designing a fillet for the juncture of wing and fuselage no longer presents a serious problem. Expanding fillets are drawn on preliminary design proposals with reasonable expectation of satisfactory functioning. When the liquid-cooled in-line engine came into use, however, the interference burble again became a problem, and new shapes had to be designed to suppress a premature stall caused by malformations at the leading edge of the wing near the fuselage. This paper deals with the latter type of stall, and particularly with the use of leading edge blisters as a remedy.

Wind-tunnel tests of an early blister indicated that the maximum speed of the aeroplane was reduced about two miles per hour thereby. More recently a blister was designed that effectively delayed the stall and at the same time provided a speed increase of three miles per hour, as indicated by tunnel tests, over the aeroplane without blisters. Possibilities of a blister that will both delay the stall and increase the speed are therefore indicated.

The Effect of Nacelle Propeller Diameter Ratio on Body Interference and on Propeller and Cooling Characteristics. (J. G. McHugh and E. H. Derring, N.A.C.A. Report No. 680, 1939.) (74/25 U.S.A.)

An investigation was conducted in the N.A.C.A. 20-foot tunnel to determine

the slipstream drag, the body interference, and the cooling characteristics of nacelle-propeller combinations with different ratios of nacelle diameter to propeller diameter. Four combinations of geometrically similar propellers and nacelles, mounted on standard wing supports, were tested with values of the ratio of nacelle diameter to propeller diameter of 0.25, 0.33 and 0.44.

The results show that (1) the effect of variation in the ratio of nacelle diameter to propeller diameter on propulsive efficiency is not important until the nacelle becomes approximately one-third of the propeller diameter, but, beyond that point, the propulsive efficiency decreases rapidly with further increase in relative body size; (2) the net efficiency of a nacelle-propeller combination decreases rapidly with increasing values of the ratio of nacelle diameter to propeller diameter; (3) the presence of a spinner over the propeller hub increases the propulsive efficiency by an amount varying from 1½ to 4 per cent.; and (4) the maximum pressure drop available with adjustable cowling flaps is about 20 per cent. greater than the maximum pressure drop available with an adjustable-length cowling skirt.

Meteorological Conditions Associated with Aircraft, Lightning Discharges and Atmospherics. (E. J. Minser, J. Aeron. Sci., Vol. 7, No. 2, Dec., 1939, pp. 51-55.) (74/26 U.S.A.)

From an analysis of a large number of actual cases, lightning discharges to aircraft in flight are determined to be between two oppositely-charged regions in cumulo type clouds and to occur most frequently in the zone adjacent to the freezing isotherm, *i.e.*, from 26° to 34°F. The origin of the electrical charge in cumulo type clouds is explained as resulting from the selective separation of positive and negative ions in the earth's electrical field by cloud and precipitation particles, and final concentration at the freezing isotherm through disruption of rain drops. Flight procedure through cumulo type clouds to avoid lightning discharges should be as follows:—

(1) Avoid, if possible, instrument flight through large cumulo-type clouds, especially at the level where the temperature is between 25° and 35°F.

(2) If, when on instruments, it is apparent from the temperature and degree of static and corona discharge that the aeroplane is in a highly-charged zone, and a discharge is imminent, reduce speed and descend.

(3) If a change in altitude is not possible and reduction of speed does not materially reduce corona or static, keep eyes focused on the instrument panel, which should be brightly lighted at night. This will help to prevent temporary blindness if a discharge occurs near the cockpit.

In no instance was a discharge encountered when this procedure was followed.

Dynamic Problems of the Tricycle Alighting Gear. (J. Wylie, J. Aeron. Sci., Vol. 7, No. 2, Dec., 1939, pp. 56-57.) (74/27 U.S.A.)

After a brief review of the research programme of the Douglas Aircraft Company on tricycle alighting gear, a mathematical analysis is developed for the longitudinal stability of the plane while taxi-ing on the ground. From this analysis certain criteria are developed for the avoidance of porpoising. A second and extremely necessary theoretical analysis of nosewheel shimmy discusses not only the cause, but also the amounts of damping that have yielded satisfactory gears. From the equations and sample figures given, routine calculation only is necessary to compute damping requirements on any installation, provided all constants are given or can be estimated.

A Simple Method of Measuring Landing and Take-off Speed. (C. L. Johnson, J. Aeron. Sci., Vol. 7, No. 2, Dec., 1939, pp. 75-76.) (74/28 U.S.A.)

The usual camera method for measuring landing and take-off speeds is cumbersome and expensive.

The alternative method proposed by the author and stated to give good results is the following:—

A swivelling pitot static head is located on the aircraft away from slipstream and boundary layer effects. The head swivels about the span-wise axis of the aircraft and the total pressure lead only is used during flight. This total pressure K is measured at the instant of ground contact (recorded electrically from the undercarriage). After coming to rest, the aircraft returns to the original landing point, faced into the wind, and the static pressure at the pitot head is measured. Provided the wind speed is not excessive, this static pressure

$= P_o =$ true static pressure away from aircraft.

Further, if $V_o =$ true landing speed,

$P_A =$ local static pressure at pitot on landing (depends on pressure distribution round aircraft),

$V_A =$ local velocity at pitot,

we have $P_o + \frac{1}{2}\rho_o V_o^2 = P_A + \frac{1}{2}\rho_A V_A^2 =$ total pressure $= K$.

Since ρ_o is nearly equal to ρ_A, true landing speed $V_o = \{ 2 (K - P_o) / \rho_o \}^{\frac{1}{2}}$

Surface Heat Transfer Coefficients of Finned Cylinders. (H. H. Ellerbrock, Jnr., and A. Biermann, N.A.C.A. Report No. 676, 1939.) (74/29 U.S.A.)

1. The surface heat-transfer coefficients of finned cylinders can be correlated for any one air-flow arrangement by plotting a factor involving the surface heat-transfer coefficients, the fin space, and the conductivity of the cooling air against a factor involving the velocity, the density and the viscosity of the cooling air and the fin space, the fin width, and the cylinder diameter.

2. A variation of the initial turbulence in the tunnel airstream for the range covered in the present tests had very little effect on the surface heat-transfer coefficient.

3. The improvement in heat transfer obtained with a fin-plane/airstream angle of 45° as compared with one of 0° is appreciably affected by the value of the space between fins.

4. The pressure difference across a finned cylinder is affected by the fin width, the cylinder diameter, and the front baffle opening in direct proportion to the effect that these three dimensions have on the length of path l as defined in the report.

Siebenthaler De-Icer Spinner. (Inter. Avia., No. 687, 5/12/39, p. 10.) (74/30 U.S.A.)

The Siebenthaler Division of the Aircraft Accessories Corp. has substantially improved its airscrew spinners, widely used by the American air-lines, and made it available for use on both Curtiss and Hamilton airscrews of all current sizes (ranging from 20 in. to 50 in. in diameter). The spinner is mounted, through the use of rubber in shear; two sets of shock mounts on either side of the blades are employed. In rotation the spinner "floats" in a balanced position; the formation of ice on the spinner destroys the condition of balance, allowing the spinner to vibrate and throw off the ice. The slinger ring with the channels to feed the de-icing fluid on to the airscrew blades is cast integral with the bottom part of the spinner.

Operating Temperatures of Air-Cooled Engine Cylinders of French Transport Aircraft. (Autom. Ind., Vol. 81, No. 11, 1/12/39, p. 572.) (74/31 France.)

The three transport machines investigated are the Potez 62, the Bloch 220 and the Dewoitine 338. The two former are twin-engined, whilst the last is a trimotor. The weights of these machines vary between 16,000 and 25,000 lb. with cruising speeds between 160 and 180 m.p.h. All three machines are fitted with Gnome-Rhone engines and modified N.A.C.A. cowlings.

The following average temperatures were noted under cruising conditions:—

Temperature °F.	Potez	Bloch	Dewoitine
Head	329	338	329
Barrel	158	158	158

Flying with one engine dead, the temperatures become

Temperature °F.	Potez	Bloch	Dewoitine
Head	446	428	392
Barrel	221	230	221

Engine Bearings—from Design to Maintenance. (A. B. Willi, J.S.A.E., Vol. 45, No. 6, Dec., 1939, pp. 513-25.) (74/32 U.S.A.)

There are six major causes of bearing failures, namely, faulty design, purchase based on incomplete specifications, misuse and abuse in operation, faulty installation, unsuitable lubricants and mechanical faults in the bearings themselves. Although there are four general types of bearing materials in common use for main and rod bearings (tin-base babbits, high-lead babbits, cadmium alloys and copper-lead mixtures), it is shown that not one of them is a universal bearing material, but each has its own particular usefulness. These fields are defined in terms of maximum unit pressure, oil reservoir temperature and crankshaft hardness. Design factors which react against indicated satisfactory performance are discussed, including strength and stiffness of the bearing structure, restrictions in feed grooves, oil clearance, etc. Design standards relating to these points are established.

Identification of failure due to misuse is illustrated by means of typical examples.

Vibration Characteristics of Aircraft Engine—Propeller Systems. (C. M. Kearns, J.S.A.E., Vol. 45, No. 6, Dec., 1939, pp. 540-8.) (74/33 U.S.A.)

Complete isolation of the aeroplane propeller from the engine, except for a very flexible torque drive, appears to be the only satisfactory solution of the vibration problem. Under such conditions much lighter propeller blades can be used to maintain even greater horse-powers than are available at present. The problem of vibration characteristics of engine and propeller when operating jointly has recently become practically the determining factor in the selection of the proper propeller for use with a given aeroplane-engine combination. An intensive investigation of this problem from both the experimental and analytical aspects is reported. The various sources of excitation and modes of motion frequently found in present-day power plants are discussed. It is estimated that if all vibratory excitations were removed from the propeller, the specific weight could be reduced to approximately 0.2 lb. per h.p. Stress measurements were made on a propeller operating at 200 per cent. power and 100 per cent. speed rating on an electric whirl rig. The stresses in this case were found to reach only 15 or 20 per cent. of the permissible alternating value for the particular design, and if it had been possible to design the propellers for this alternating stress, a weight reduction of 0.13 lb. per h.p. could be realised.

Stored Energy. (Fuel, Vol. 18, No. 12, Dec., 1939, p. 355. Mech. Eng., Nov., 1939.) (74/34 Great Britain.)

In connection with the study of auxiliary power in aeroplanes, a computation has been made of the weight of various sources of energy with respect to both the weight of the material and the weight of the container, where the latter is required. The following table gives the weights per kw.-hr. of certain sources of energy, as well as the total weight including the container:—

	Weight, lb. per kw. hr.	Total weight, lb. per kw. hr.
Gasoline	0.18	0.20
H_2 gas (in cylinder)	0.06	3.03
H_2 liquid	0.06	0.18
Cartridge	2.78	5.56
Dry battery	45—65	45—65
Storage battery	108	108
Compressed air (100 lb. per sq. in.)	281	881
Compressed air (1,000 lb. per sq. in.)	128	401
Flywheel	302	302
Rubber	1,292	1,292
Steel spring	443,000	443,000

Problems of Submerged Engine Installations. (Inter. Avia., No. 689, 19/12/39, pp. 1-4.) (74/35 Switzerland.)

The main problems confronting the aircraft designer interested in submerged engine installations can be summarised as follows: (1) the design of a satisfactory propeller shaft; (2) the satisfactory and safe disposal of the exhaust gases; (3) cooling of the engine compartment, cylinders, supercharged air, lubricating oil, accessories and exhaust disposal system; (4) the mounting of the engine. In spite of these difficulties, the authors are of the opinion that the advantages of the submerged engine installation makes the solution of the problem worth while. The gains of such a design are almost entirely in the field of aerodynamic performance; increased propulsive efficiency due to the lack of propeller interference with the nacelles; increased lift because the much smaller extension shafts do not blanket or prematurely stall the wing as is the case with the larger nacelles; the reduction of drag due to the elimination of the large nacelles; and the elimination of wing-nacelle interference. Performance calculations on two practically identical aircraft, one with submerged engines and the other with conventional nacelle air-cooled engines of the same power, showed a gain in speed of approximately 7 to 8 per cent. in favour of the submerged installation.

Design of High-Speed Gears. (K. Knibble, J. Aeron. Sci., Vol. 7, No. 2, Dec., 1939, pp. 68-71.) (74/36 U.S.A.)

Designing a successful reduction gear to handle power outputs of modern aircraft engines in excess of 1,000 h.p. has proved to be a very difficult problem.

In the average high speed application, the conventional tooth strength is not the controlling factor. The final step is in the so-called "Wear Factor." This is a function of the surface stresses on the tooth flank. The purpose of the present paper is to supplement this last and most important phase of the gear problem.

The stress on the tooth surface depends upon the radii of curvature as worked out by Hertz.

Upon this is based a method to determine the maximum energy that can be safely transmitted from one gear to another during one revolution.

This quantity of energy, divided by the square of the diameter of the pinion and a constant is called "power-function of the gear" and is a dimensionless quantity. It can be easily determined by a tooth form layout to any enlarged scale.

This power function is calculated with various pressure angles, addenda, and gear ratios.

The above has been applied to actual gears built, and it was found that whenever the power function was increased, the wear qualities also improved. There was no opportunity to test the theory quantitatively.

U.S.A. Aviation Fuel. (Inter. Avia., No. 687, 5/12/39, p. 11.) (74/37 U.S.A.)

With the increase in production of the American aviation industry to meet American defence requirements and the export demand and, perhaps, also due to the beginning of the war, the American petrol industry was faced with the problem of how to increase the output of high octane aviation fuel. The present annual consumption of anti-knock aviation fuels in the U.S.A. alone is estimated at 20,000,000 U.S. gals., and the present annual output is estimated at 37,000,000 gals. By the expansion of existing plants and the erection of new ones, this production is to be stepped up to 125,000,000 U.S. gals. annually within one year. Greater quantities of fuel would then be available for export. The Standard Oil Development Company is understood to be specially concerned in the development of anti-knock fuels.

The Characteristics of Atmospheric Type Burners when Used with Natural Gas. (E. D. Howe and H. Johnson, Trans. A.S.M.E., Vol. 61, No. 8, Nov., 1939, pp. 673-7.) (74/38 U.S.A.)

In this paper it is determined that the design of atmospheric-type gas burners depends upon the stability of the flame produced, which is related to the speed of flame propagation in the combustible mixture. Experiments made upon single-port gas burners have served to show that the effective velocity of flame propagation is greater than the velocity of flame propagation in still mixtures.

Lubricants from Fish Oil. (Ind. and Eng. Chem. (Industrial Edition), Vol. 17, No. 22, 20/11/39, p. 710.) (74/39 Japan.)

The Japan Oil and Fat Company has decided to industrialise its process of manufacturing aircraft lubricants from fish oil. A site for the plant has been selected near Japan Oil's Amagasaki factory. Besides whale oil, sardine and herring oils will serve as raw materials. The oil produced by the company's secret process is supposed to be superior in quality.

Researches on the Activity of Castor Oil. (J. J. Trillat and P. Nardin, Pub. Sci. et Tech., No. 152, 1939.) (74/40 France.)

The surface tension between two liquid phases is considerably modified by presence of other substances in one of the phases, owing to adsorption in the transitional layer of molecules or particles capable of modifying the total energy of the system. Considering an oil as a mixture of active and neutral molecules, it is to be expected that the concentration of one type of molecules will be modified in the separation layer oil/liquid, causing a variation in surface tension. Systematic study of this phenomenon as a function of time has previously been carried out by putting distilled water into contact with a pure paraffin oil (neutral molecules) in which increasing quantities of oleic acid (active molecules) are dissolved. In the present paper measurements have been made of the interfacial tension of pure water in contact with specifically active oils, i.e., consisting entirely of active molecules. With these oils there was again found a lowering in interfacial tension in relation to time of contact. In this case the interfacial tension is a function of the orientation of the molecules in the transitional layer and the recorded curves show the variations of this orientation as a function of time. It is deduced that organisation of the molecules takes place rapidly at the commencement of contact and then is completed slowly. With increasing temperature the recorded variations in interfacial tension decrease and are practically eliminated at about 40°C. Since castor oil is practically insoluble in water it is mainly the phenomena of orientation at the interface which cause these variations and it is thus possible to interpret the effect of temperature.

Thermal Study of the Oxidation of Motor Fuels. (Mme. Dufour-Estradère, Pub. Sci. et Tech., No. 154, 1939.) (74/41 France.)

An experimental study is made of the mechanism of the slow oxidation of hydrocarbons, which, as has previously been shown by the author, takes place in successive stages. The thermal effects of these reactions are studied and it is shown that in certain cases the laws of the kinetics of chain reactions are defective. It is then a matter of reactions in "thermo-accelerated ramified chains." The conditions in which cracking plays a part during the course of oxidation is also examined, this effect varying greatly according to the hydrocarbon concerned. Passing to the study of petrols it is shown that the thermal effect accompanying their oxidation is all the more feeble as the octane number is higher, even if the high octane number is the result of addition of an anti-detonating agent.

1. CONTENTS.—Combustion of hydrocarbons, successive phases of oxidation in the temperature scale; kinetic laws governing the combustion of hydrocarbons; interpretation of the thermal diagrams for pentane according to these laws. 2. Occurrence of cracking during oxidation; method of investigation; relation between cracking and knock susceptibility. 3. Diversity of observations made during thermal analysis by the method described. 4. Possibility of generalisation of the kinetic laws and application of thermal analysis to the study of petrols.

Problems of Mass Production of Aircraft. (Luftwissen, Vol. 6, No. 7, July, 1939, pp. 223-224.) (74/42 Germany.)

At a recent meeting of the Lilienthal Society, a number of papers were presented dealing with the subject of production. The following are some of the conclusions reached.

1. From the point of view of efficiency and cost it is advantageous to carry out the entire manufacturing process under one roof. This, unfortunately, conflicts with A.R.P. requirements.

2. For a given factory, the man-hours required per aircraft depend on the number of machines passing through the shops and the position in the series. As a result of extensive research it is now possible to estimate the total time for a series if the man-hours for the prototype are known.

3. In order to stimulate production, a wage bonus is paid depending on the position of the machine in the series. This bonus in some cases depends also on the amount of skill required by the workman.

4. Changes in design during production add enormously to the cost and for this reason sufficient time must be allowed for the first series to incorporate any necessary modifications. Large scale production should only be started after complete agreement has been reached between the design and production departments.

5. Cost can be reduced and floor space saved by reducing the number of special appliances, jigs, etc., to the utmost. Those ultimately retained should, if possible, always serve a variety of purposes and be made of the cheapest material.

6. A further effective way of reducing costs consists in modifying manufacturing processes, e.g., the extensive use of pressed components instead of riveted assemblies.

Shear Field Aircraft Spars. (J. E. Lipp, J. Aeron. Sci., Vol. 7, No. 1, Nov., 1939, pp. 1-5.) (74/43 U.S.A.)

Experience has shown that the intrinsic cost of manufacture of shear-web spars (Wagner type) is the lowest of all types of spars.

Apart from low cost, an aircraft spar must possess other features, chief of which are:—

1. Low vulnerability (high degree of redundancy).

2. Low weight.
3. High rigidity.

From investigation carried out by the Douglas Aircraft Co., it appears that the Wagner type of shear field spar fulfils the above requirements and has therefore been generally chosen for wing and tail surface construction.

The author describes how thickness of web and size of stiffeners can be selected to fulfil certain load conditions.

Web thicknesses may range from .02 to .08 inches and above. The allowable shear stress increases with thickness of sheet from 18,000 lb./in.^{2} at 0.2 to 25,000 lb./in.^{2} at .08 for 24 Stal material.

Webs thinner than .02 in. are not used on account of riveting difficulties.

Occasionally a large access hole must be put through a spar web. In this case the type of framework around the hole depends upon the loads involved. An efficient type developed by the Douglas Company is in the form of a diagonal truss, the truss members being made of extruded bulb angles fastened to the web surrounding the hole. Gussets are added at the four corners of the diamond.

Synthetic Bearings for Rolling Mills. (C. D. Phillipe, Met. Ind., 15/12/39, pp. 503-6. Met. Vick. Tech. News Bull., No. 690, 22/12/39, p. 5.) (74/44 Great Britain.)

In this article, the author classifies plastics as thermoplastic, or as thermohardening materials and describes the manufacture and properties of the phenol-formaldehyde resins which he places in the latter classification. The main classes of material derived from these resins are (1) moulding materials, (2) paints, varnishes and lacquers, (3) laminated materials. The manufacture and characteristics of laminated materials are described and points, economic and mechanical, which are in favour of the use of these materials as bearings, are listed. Some practical applications will be discussed in a subsequent article.

Illustrated with one photograph and three diagrams.

A Rapid Method for Determining Carbon in Plain Carbon Steels for Control Purposes. (Trans. A.F.A., Dec., 1939, pp. 469-90. Met. Vickers Tech. News Bull., No. 690, 22/12/39, p. 10.) (74/45 U.S.A.)

The method described in this article consists of comparing the magnetic permeability of a bar of known carbon content, with the magnetic permeability of the bar of unknown carbon content. The actual magnetic permeabilities are not measured, but the effect of the difference in induced emf. existing in coils, by the collapse of induced magnetic flux is measured with a ballistic galvanometer. The deflection of the galvanometer depends on the difference of carbon content in the two bars. It is claimed that the time taken in determining carbon content of steels by this method is not over 2.5 min. as compared with 5 min. or over for chemical methods. The effect of alloying elements, such as manganese, silicon, nickel and molybdenum on the accuracy of the method are discussed.

Illustrated with one photograph, one diagram and four graphs.

Bearing Testing Machine for Different Types of Loads. (E. A. Cornelius and E. H. Barten, Z.V.D.I., 18/11/39, pp. 1219-21. Met. Vick. Tech. News Bull., No. 690, 22/12/39, p. 6.) (74/46 Germany.)

The authors describe a new machine developed for the purpose of carrying out tests, in one machine, on bearings under loads of different types (rotating, sinusoidally oscillating, rapidly variable, combined). They give details of the design and principle of operation of the machine, also of the trial run and the first test results obtained.

Illustrated with four diagrams and two photographs.

Testing Gear Wheel Material. (A. Meldahl, B.B. Rev., Oct., 1939, pp. 235-40. Met. Vickers Tech. News Bull., No. 690, 22/12/39, p. 6.) (74/47 Great Britain.)

In connection with gear wheel material testing, the author points out the desirability of using test pieces of simple design, and that in order to reproduce faithfully the conditions pertaining to teeth faces, it is necessary to generate a sliding movement, as well as a rolling movement, between the test faces. Apparatus in which it is claimed that these conditions are satisfied is described in this article. Results of tests are given, and the operation of the machine is investigated from a kinematical point of view.

Illustrated with two diagrams, eleven photographs and one graph.

Heat Treatment Department. (J. Bentley, El. Engineer, 15/12/39, pp. 190-3. Met. Vickers Tech. News Bull., No. 690, 22/12/39, p. 8.) (74/48 Great Britain.)

This article deals with the electrical installation and equipment of a heat treatment department. The author discusses the size and rating of furnaces, and in connection with choice of resistance material, the use of nickel chrome alloy is advocated. Supply transformers, temperature control devices, contactor and busbar arrangements are discussed and notes on the control of maximum demand are given. The position of control instruments and thermocouple leads is discussed.

Illustrated with six diagrams and one photograph.

Preparation of Metals in a Compact Form by Pressing and Sintering. (J. D. Fast, Philips Tech. Rev., Nov., 1939, pp. 310-6. Met. Vickers Tech. News Bull., No. 690, 22/12/39, p. 9.) (74/49 Great Britain.)

Due to their high melting points, the metals tungsten, molybdenum tantalum, etc., cannot easily be melted or cast. These metals can, however, be prepared in powder form. This article describes the preparation of the compact metal, by methods of powder metallurgy. A general discussion is given of the preparation and working of ductile tungsten for the electric lamp industry and the preparation and use of hard cemented carbides as cutting tools is reviewed. The use of self-lubricating bearings, prepared by powder metallurgical methods, is noted.

Illustrated with two diagrams and six photographs.

Vulcanisation of Rubber. (H. L. Fisher, Ind. and Eng. Chem. (Industrial Edition), Vol. 31, No. 11, Nov., 1939, pp. 1381-1389.) (74/50 U.S.A.)

The early history of vulcanisation and the beneficial changes wrought on rubber by Goodyear's famous process are reviewed. An outline is given of the methods used in vulcanisation, the principal facts, and the theoretical considerations of the chemistry involved. Non-sulphur vulcanising agents are listed, including some not previously described (yellow mercuric oxide, and the combination of phenols and oxidising agents). A comparison of their chemical activity brings forth the generalisation that probably in all cases a reduction and an oxidation take place. If the agent is already in the reduced state, then it is necessary to add an oxidising agent. An oxidising agent generally makes a better vulcanisate with almost all non-sulphur agents. The reduced form probably adds to the rubber hydrocarbon, and this addition product is then oxidised to make the vulcanisate.

Since all vulcanisates have certain characteristics in common, it is postulated by analogy that some of the sulphur during vulcanisation is reduced to hydrogen sulphide, that the hydrogen sulphide adds to the rubber hydrocarbon forming a mercaptan, and that this mercaptan is oxidised by some of the sulphur to form a disulphide which may connect two sections of the same or of two different molecules. It is shown that many of the facts of sulphur vulcanisation are explained by this theory.

Determination of Cross-Sectional Areas of Structural Members. (J. A. Miller, Bur. Stan. J. Res., Vol. 23, No. 5, November, 1939, pp. 621-636.) (74/51 U.S.A.)

The cross-sectional areas of structural members are often required for computing the stresses corresponding to the applied loads. The areas of many light-weight members cannot be obtained accurately from either nominal or measured dimensions. For example, in thin-walled members small differences in thickness cause large percentage errors in area. Moreover, the shape of a section may not permit adequate measurements of the dimensions required to calculate the area. In such cases it is often advantageous to obtain the average cross-sectional area by a volumetric method if the cross-section is uniform. If the cross-section varies in area from section to section the area of a given section can sometimes be obtained from the average area of a short specimen taken from that location.

The method is illustrated by a determination of cross-sectional area for a typical airship box girder, fabricated from sheet aluminium alloy. The cross-sectional area varied because of a row of flanged circular lightening holes along each side and was a minimum at sections through the centres of the holes. Specimens 0.3 inch long were taken symmetrical to a minimum section. The end surfaces were ground smooth and nominally parallel so that the lengths could be measured accurately. The volume was determined by hydrostatic weighing. A correction was applied to the average cross-sectional area of these specimens to obtain the minimum cross-sectional area. The estimated uncertainty of the determination was ± 0.4 per cent.

Stress Functions for a Plate Containing Groups of Circular Holes. (R. C. J. Howland and R. C. Knight, Vol. 238, No. 793, 24/11/39.) (74/52 Great Britain.)

A number of solutions of the biharmonic equation have been obtained, mostly in connection with the problems of generalised plane stress, when the boundaries have consisted of circles and straight lines. No general method of solution can be given but the methods which the present authors have used in certain cases are here extended to a group of problems. The paper deals with circles in (a) the infinite plane, (b) a strip bounded by parallel lines. The circles, their numbers and relative positions, are restricted by an invariancy condition, which demands that the circles and their boundary conditions remain invariant under one or more of a group of transformations and/or reflections.

In (a) the configurations have the boundaries (i) one pair of circles, (ii) two pairs of circles, (iii) a double infinite row of circles. While in (b) (i) one pair, and (ii) two pairs of circles are dealt with. These together with solutions previously published complete the group of problems to which the method is applicable.

A Recurrence Formula for Shear-Lag Problems. (P. Kuhn, N.A.C.A. Tech. Note No. 739, Dec., 1939.) (74/53 U.S.A.)

The analysis of the bending action in box beams with appreciable shear deformation of the flanges becomes very difficult in the general case of variable cross-section and loading. This paper presents a convenient method of solving the problem by the familiar method of dividing the beam into a number of bays that can be assumed to have constant cross-section and loading. Application of formerly derived shear-lag formulas leads to a general equation closely analogous in form to the well-known three-moment equation. A numerical example and two comparisons between calculation and experimental results are included. In one of these cases the agreement is satisfactory. Discrepancies in the other case may be due to faulty material.

Stress Concentration Around an Open Circular Hole in a Plate Subjected to Bending Normal to the Plane of the Plate. (C. Dumont, N.A.C.A. Tech. Note No. 740, Dec., 1939.) (74/54 U.S.A.)

The test results obtained with a plate containing an open circular hole, whose diameter is relatively large compared with the thickness of the plate and subjected to uniform bending normal to the plane of the plate may be summarised as follows:

1. Stress concentrations occurred at the edge of the hole, the maximum stresses being tangential to the hole at the ends of the transverse diameter.

2. The maximum stress at the edge of the hole was 1.59 times the computed stress on the net section and 1.85 times the computed stress in a solid plate of the same dimensions subjected to the same bending forces.

3. The smallest edge distance was equal to 2-1/2 times the diameter of the hole, and the stress concentration on this side of the hole was the same as on the side where the edge distance was about 4-1/2 diameters.

4. A theoretical analysis of the problem shows that, for an aluminium plate of infinite width, the stress concentration at the edge of the hole would be 1.87 times the stress in a solid plate, which is substantially the same relation obtained on the plate tested.

5. From the foregoing, it may be concluded that the stress-concentration factor based on gross area would be the same for any width of plate provided that the edge distance was at least 2-1/2 diameters.

6. The maximum deflections were about 20 per cent. greater than the corresponding deflection for a solid plate of the same size subjected to the same bending forces.

Tide Water and Weather Exposure Tests on Metals Used in Aircraft. (W. Mutchler and W. G. Galvin, N.A.C.A. Tech. Note No. 736, Nov., 1939.) (74/55 U.S.A.)

Tide water and weather exposure tests on various aluminium alloys, magnesium alloys, and stainless steels are now being conducted by the National Bureau of Standards. Exposures were begun in June, 1938, and, according to present plans, are to continue over a three-year period. The methods of exposure and the materials being investigated are described and some of the more important results obtained up to the conclusion of the first year's exposure are given below.

1. Alloy 52S-1/2H (a binary alloy containing app. 2.5 per cent. Mg.) is the most corrosive resistant of the A1 alloys tested and also the one least attacked when in contact with other A1 alloys, magnesium alloys or stainless steels.

2. Stainless steel containing Mb proved more resistant than the normal varieties. An alloy containing 16 per cent. Cr and 1 per cent. Ni was very much more corroded than the other stainless steels.

3. Magnesium alloys are much more susceptible to attack than either A1 alloys or stainless steels. Contact between magnesium alloys and stainless steels should specially be avoided.

4. Magnesium alloys can be adequately protected against very severe corrosive conditions by suitable choice of surface treatment and paints applied.

Photo-Elastic Analysis of Three-Dimensional Stress Systems Using Scattered Light. (R. Weller and J. K. Bussey, N.A.C.A. Tech. Note No. 737, Nov., 1939.) (74/56 U.S.A.)

A method has been developed for making photo-elastic analyses of three-dimensional stress systems by utilising the polarisation phenomena associated with the scattering of light. By this method, the maximum shear and the directions of the three principal stresses at any point within a model can be determined, and the two principal stresses at a free-bounding surface can be separately evaluated. Polarised light is projected into the model through a slit so that it illuminates a

plane section. The light is continuously analysed along its path by scattering and the state of stress in the illuminated section is obtained. By means of a series of such sections, the entire stress field may be explored. The method was used to analyse the stress system of a simple beam in bending. The results were found to be in good agreement with those expected from elementary theory.

Research into Corrosion and the Protection of Light Alloys. (A. von Zeerleder, Inter. Avia., No. 690, 29/12/39, pp. 1-4.) (74/57 Switzerland.)

According to the type of attack, one may distinguish between general, local and intercrystalline corrosion.

General corrosion is uniformly distributed over the entire surface of the metal and can only occur if the corrosive media dissolve the oxide film which normally acts as a protection.

Local corrosion is provoked by local galvanic couples due to the presence of heterogeneous alloy particles or impurities in the surface or simply due to uneven oxygen distribution over the surface. In this case the corrosive agent does not act as an oxide film solvent but as an electrolyte for the local couples.

Intercrystalline corrosion is the most dangerous form of attack, since it disintegrates the material internally without much apparent surface effect.

Aluminium alloys containing copper or magnesium are particularly liable to this last form of corrosion if the heat treatment is incorrect.

In the case of alloys of the Dural type, experiments have shown that the time interval between tempering and quenching is of importance in determining tendency to intercrystalline corrosion. The exposure time to the air, between these two operations must be short enough (a few seconds) to prevent the precipitation of alumide of copper as a continuous film in the intergranular space.

This film is less " noble " than the mixed crystals of the alloy and is thus liable to be dissolved by the formation of galvanic couples in the presence of an electrolyte.

The Buckling of Spherical Shells by External Pressure. (Th. von Kármán and H. S. Tsien, J. Aeron. Sci., Vol. 7, No. 2, Dec., 1939, pp. 43-50.) (74/58 U.S.A.)

Up to now considerable discrepancy has existed between theory and experiment in the case of the buckling of spherical shells under uniform external pressure. It appears that the experimental buckling load is of the order of $\frac{1}{4}$ of the theoretical value. Whilst theory indicates a wave form extending over the whole spherical surface with no preference as regards inward or outward buckling, the experiments show a definite preference to buckling inward, the buckling wave being, however, restricted to a relatively small dimple. The author removes the discrepancy by showing that there exists an "upper" buckling load given by the classical theory of infinitely small deflections and a " lower " buckling load which is equal to the minimum load necessary to keep the shell in a buckled state with a finite deflection. The essential feature of his theory is that the lower buckling load is determined independently of initial imperfections of the specimen or load arrangement.

The upper limit of the buckling load can only be approached experimentally if extreme precautions are taken and the lower value is the one to be specified for design.

A Fixture for Obtaining Pin-End Conditions in Column Testing. (H. W. Barlow, J. Aeron. Sci., Vol. 7, No. 2, Dec., 1939, pp. 72-74.) (74/59 U.S.A.)

Difficulties attending the use of rollers, knife-edges and other devices used for obtaining ideal hinged-end conditions for tests of columns are discussed briefly. A new testing fixture is described which incorporates ball-bearing assemblies and gives hinged-end results for specimens having flat, parallel ends. Corrections for effective free-lengths are unnecessary. Results of tests on columns fabricated

from thin stainless steel sheets are given to indicate the quality of the results. Possibilities for improvements and further application to tests of elastically restrained columns, eccentrically loaded columns, and sheet-stringer combinations are suggested. The ball-bearing assemblies utilised have the advantage of being commercial products and at the same time extremely accurate.

Stroboscopic Light Source. (H. E. Kallmann, Proc. Inst. Rad. Eng., Vol. 27, No. 11, Nov., 1939, pp. 690-692.) (74/60 U.S.A.)

Stroboscopic light sources are widely used for observation of fast movements. The use of mechanical light-chopping devices is restricted to low frequencies, and is generally inferior to gas-discharge lamps, which are very satisfactory up to flash frequencies of about 20 kilocycles but at higher flash frequencies seem to become impracticable because the inertia of gas molecules prevents an adequately quick discharge. Only spark discharges can at present be used for observation of the very fast movements of sound waves or of projectiles.

The author describes an alternative method in which a blocking oscillator is used, producing short pulses of several ampères of anode current in a vacuum tube. The anode is covered with fluorescent material which thus produces the stroboscopic flash, which may readily reach 10,000 candle power. Flash frequencies of the order of 200,000/sec. can be obtained, each flash lasting about 1/5,000 sec.

The Anode Tank Circuit Magnetron. (E. G. Linder, Proc. Inst. Rad. Eng., Vol. 27, No. 11, Nov., 1939, pp. 732-738.) (74/61 U.S.A.)

A new type of magnetron is described in which the split cylindrical anode is made approximately one-quarter wave in length, the two segments being short-circuited at one end. The anode resonates and acts as a tank circuit. Thus difficulties due to interelectrode capacitance and tube lead inductance are circumvented and a much greater heat radiating area is provided. An output of 20 watts at 3,750 megacycles (8 centimetres wavelength) and an efficiency of 22 per cent. is obtainable. The theory of the anode tank circuit is developed, and expressions are given for wavelength, internal resistance, and logarithmic decrement.

Ultra High Wireless Frequencies and Their Application to Aeronautics. (W. E. Jackson, J. Aeron. Sci., Vol. 7, No. 1, Nov., 1939, pp. 28-29.) (74/62 U.S.A.)

At the present moment most aviation aids for civil aircraft in the U.S.A. operate on a frequency range of 200--400 kilocycles. Frequencies of this order are subject to atmospheric interference, rain, snow and dust static and multiple course phenomena caused by reflections from the earth's surface. Recently a number of position markers operating at a frequency of 75 megacycles have been installed. These markers are known as the "Z" (or "positive cone of silence marker") and fan (F.M.) markers respectively. The former is intended to mark the instant the aircraft passes over the markers, whilst the fan marker, by the elliptic shape of its field pattern, gives positive indication of a traffic control reporting point on the airway. Both markers in addition to providing audio signals in the headphones also operate lights in the cockpit.

Another application of ultra-high frequencies is to provide a system of instrument landing. The elements of such a system are the localiser, glide path and markers. The localiser is a visual type of radio range whilst the glide path is a vertical plane field pattern contour of constant field strength. Inner markers are located at the edge of the field whilst the outer markers are situated at a distance of approximately 2 miles. The localiser operates at a frequency of 109.9 megacycles whilst the glide path has a frequency of 93.9 megacycles.

A trial system working on the above lines is being installed by the Civil Aeronautics Authority at Indianopolis. Development work is proceeding in order to

obtain a straight line glide path which appears to offer several important advantages.

Results obtained so far with ultra-high frequencies are very encouraging and such frequencies will play an important part in aviation of the future.

Apparatus for Magnetic Testing at Magnetising Forces up to 5,000 Oersteds. (R. L. Sanford and E. G. Bennett, Bur. Stan. J. Res., Sept., 1939, pp. 415-25. Met. Vick. Tech. News Bull. No. 690, 22/12/39, p. 10.) (74/63 U.S.A.)

This article describes an apparatus for general magnetic testing in the range of values of magnetising force from 100 to 5,000 oersteds. Specimens of rectangular cross-section up to 3.8 cms. wide and 1.9 cms. thick can be tested. It is estimated that under favourable conditions values of induction or magnetising force accurate within 0.5 per cent. can be obtained and that under ordinary conditions of routine testing, the accuracy is within 1 per cent. Details of experiments carried out to determine the distribution of flux in the specimen are given. It is claimed that this apparatus is simple to operate, and does not heat the specimen.

Illustrated with two photographs, four graphs and one diagram.

The Electrical Resistance of Metal Contacts. (J. J. Went, Philips Tech. Rev., Nov., 1939, pp. 332-5. Met. Vickers Tech. News Bull., No. 690, 22/11/39, p. 9.) (74/64 Great Britain.)

The electrical resistance of contacts depends in the first instance upon the specific resistance of the material of the contacts, the hardness of the material, and the contact pressure. In addition, the properties of the surface of contacts are also important. On the basis of these factors, a study is made in this article, of the methods by which a high resistance contact may be improved.

Illustrated with two graphs and two diagrams.

LIST OF SELECTED TRANSLATIONS.

NOTE.—Applications for the loan of copies of translations mentioned below should be addressed to the Under-Secretary of State (R.T.P.), Air Ministry, Dept. Z.A., London, W.C.2, and will be supplied as far as availability of stocks permit. Suggestions concerning new translations will be considered in relation to general interest and facilities available.

Lists of selected translations have appeared in this publication since September, 1938.

THEORY OF WARFARE.

TRANSLATION NUMBER AND AUTHOR.	TITLE AND JOURNAL.
985 Possio, C.	*Lateral Firing from Aircraft.* (Turin Polytechnic Aeronautical Laboratory Report, No. 120, March, 1939, XVII.)
999 Templehof von ...	*Improvements in the Technique and Tactics of Gas Warfare Since the Great War.* (Z.G.S.S., Vol. 34, No. 5, May, 1939, pp. 148-51.)

AERO AND HYDRODYNAMICS.

980 Sottorf, W.	*New Method for Determining the Full-Scale Gliding Resistance of Floats and Boats from Model Experiments.* (L.F.F., Vol. 16, No. 8, 20/8/39, pp. 412-8.)

TRANSLATION NUMBER AND AUTHOR.		TITLE AND JOURNAL.
996	Gurgienko, G. ...	*The Consideration of the Viscosity Effect in the Kármán Turbulence Theory.* (Trans. C.A.H.I., No. 322 (Moscow), 1937, pp. 1-22.)
		AIRCRAFT.
970	Litkin, S. G. ...	*Investigation of a Radiator in the Wing of an Aeroplane.* (C.A.H.I., Moscow, Tech. Note, No. 147, 1937.)
977	Fokin ... ... Smirnov	*The Magnetic Compass in Blind Flight.* (Civil Aviation, U.S.S.R., Vol. 9, No. 5, May, 1939, pp. 11-14.)
		ENGINES, FUELS AND ACCESSORIES.
953	Gnam, E. ... ... Kurz, F.	*Experiments on the High Altitude Behaviour of a High Speed Single Cylinder Engine.* (Jahrbuch der deutschen Luftfahrtforschung, 1938, Vol. 2, pp. 16-23.)
990	Seeber, F.	*Fuels for Aero Engines.* (Luftwissen, Vol. 5, No. 9, Sept., 1938, pp. 321-330.)
992	Ide, H.	*The Dynamics of Supercharger Drives on Aircraft.* (Jahrbuch der deutschen Luftfahrtforschung, 1938, Vol. 2, pp. 210-214.)
		SOUND, LIGHT AND HEAT.
944	Ernsthausen, W. ...	*Sound Radiator Groups with Rotating Phase.* (Jahrbuch der deutschen Luftfahrtforschung, 1938, Vol. 3, pp. 46-52.)
976	Dadaian, A. T. ... Pumper, E. J. ...	*Measurement of the Absorption of Supersonic Waves in Air and in Argon.* (Comptes Rendus de L'Acad. des Sciences de l'U.S.S.R., Vol. 22, No. 7-8, 15/9/39, pp. 539-542.)
		WIRELESS AND ELECTRICITY.
955	Czerlinsky, E. ...	*A High Speed Electrical Switch for Recording with a Cathode Ray Tube and Rotary Drum Camera.* (Jahrbuch der deutschen Luftfahrtforschung, 1938, Vol. 2, p. 376.)
994	Dziewior, K. ...	*Summary of Known Suggestions for Determination of Distance and for Reflected Beam Direction Finding by Wireless Means, and their Critical Consideration.* (L.F.F., Vol. 16, No. 6, June, 1939, pp. 326-338.)
		MISCELLANEOUS.
986	Meyer zur ... ... Capellen, W. ...	*Approximate Calculation of Characteristic Numbers.* (Ing. Archiv., Vol. 10, No. 3, June, 1939, pp. 167-174.)

REVIEWS.

Aircraft Engine Maintenance.

G. Daniel, J. Brinns, Jr., and H. Edward Boggess. Published by Sir Isaac Pitman & Sons, Ltd. Price 10s. 6d.

This book, though published by an English firm, is really an American textbook, as both authors are American and illustrations are all drawn from American practice. It is printed in that peculiar type, resembling typewriting, which is now becoming usual in textbooks from that country, and which is stated to reduce the costs of production. It is perfectly satisfactory in a book of this sort, being clear and easy to read.

The book, generally, is extremely well done. It is almost impossible to imagine that the operations of servicing and overhauling aero engines could be more clearly explained, and there is a special indexing system which has been devised to enable anything wanted to be easily turned up. The scope of the book, within its own field, is most comprehensive, everything that an engine mechanic wants to know seems to be given in ample detail. The reader is even given elementary lessons in mechanics, heat and electricity in order that he may understand more clearly the subject matter.

The book is also copiously illustrated. Where these illustrations are from line blocks they are good and clear, but many of the half-tone illustrations are murky and indistinct. This does not seem to be due to any defect in the blocks, but to the paper used. This matter should receive attention in future editions.

As a detailed description of modern practice in the maintenance of aero engines, this book is extremely good, and although there is no reference to British engines these are not so dissimilar to the American as to make the book inapplicable. It can be thoroughly recommended to all those interested.

Safety in the Operation of Air Transportation.

A James Jackson Cabot Professorship Lecture by Jerome Lederer. Norwich University, Vermont, U.S.A. 1939. $.50.

This is the fourth James Jackson Cabot lecture to be published, and it lives up to the importance of its predecessors. For those who have not had the opportunity of reading these lectures the titles of those already published may be recalled, International Aeronautic Organisations and the Control of Air Navigation by John Jay Ide; The Early History of Air Transportation by E. P. Warner; and Technical Development and its Effect on Air Transportation by E. P. Warner.

These lectures, and those which are in preparation, all deal with air transport, its safety, economics and technical development. They are lectures which should be read by everyone who is engaged in civil aviation, for their usefulness is of a high order.

In the case of the particular lecture under review, Mr. Jerome Lederer is well-known on both sides of the Atlantic as the Chief Engineer of Aero Insurance Underwriters and his experience of supervising aircraft corporations and in analysing the risks of aircraft for insurance purposes, both civil and military, is extremely wide.

Step by step Mr. Lederer details the progressive stages which have led to greater safety in commercial flying. His lecture is a most excellent summary, particularly

of American practice, of the precautions which are taken to foresee every emergency. Many of these precautions, now standard, have only been arrived at by bitter experience. It seems almost beyond belief that at one time commercial aircraft were diluting their petrol with water. Many aircraft at one time were refuelled from underground tanks into which rain had seeped. One machine which refused to get off the aerodrome after refuelling was found to have no less than 60 gallons of water in the tanks. Now, tests are carried out regularly to see that no water is present, as the author remarks "experience is the best teacher," and designers, manufacturers and operators, no matter how careful they are, cannot foresee all the possibilities of accidents.

It is interesting to note the lecturer's comments on the danger period of a pilot's life. "It occurs when he has about 300 hours of flying time. His confidence seems to exceed his ability in that region and his mortality rate is about 40 per thousand (flying at the rate of 400 hours per year). As his experience increases from this point, his mortality rate goes down to 15 per thousand at 800 hours. When he gets to 1,000 hours his rate goes up to about 20 per thousand and remains there. These figures are from the Actuarial Society of America."

Of the future the lecturer sums up:—

"The future should bring an accelerated record for safety, because of refinement in power plant construction, such as direct injection carburation; improvements in cowling and in fuel and oil installations to reduce fire hazards; stall warning indicators; use of anti-stalling devices; improvement in wing sections; improved performance with partial power plant failure; better undercarriage structures; more accurate altimeters or Terrain clearance indicators; radio static elimination; larger airports with clearer approaches; advance in our knowledge of vibration prevention; continuous research in structure, aerodynamics, meteorology, and metallurgy; improved methods of orientation and navigation; and especially study of pilot psychology and fatigue."

One might say almost that all the above points are obvious, but it is not by the improvement of any one of them that the ultimate high standard of safety will be reached. The part may let down the whole, and it is only by constant attention to every part and every thing involved in flying that safety will be attained.

Mr. Lederer gives statistics of the interest in flying in the United States from 1933 to 1938. The reviewer is not prepared to accept, however, the statement "But, on the basis of passenger miles flown, it is safe to say that travelling in an aeroplane operated by one of the air-lines approved by the civil aeronautic authority is no more hazardous than travelling in the ordinary passenger automobile. Furthermore, in comparison with the air-lines of the rest of the world, the safety of our scheduled air-lines is so superior that there is no real safety competition. Foreign figures are available only up to 1936. In that year the miles flown per fatal accident shows a difference of 280 per cent. in favour of the United States (7,330,384 versus 1,939,502)."

The following is an extract from the 1938 Annual Report on Civil Aviation issued by the Department of Civil Aviation, Air Ministry:—

"Approximately 4,500,000 passenger miles were flown on the regular services in 1938 for each passenger killed, while 3,400,000 aircraft miles were flown per fatal accident. For the seven year period 1932-38 the corresponding figures were 3,685,000 and 2,050,000 respectively."

MR. TOMKINS IN WONDERLAND.

G. Gamow, Cambridge University Press. 1939. 7s. 6d.

Professor G. Gamow, Professor of Theoretical Physics at the George Washington University, has written, and John Hookham has illustrated, a book which will be a delight to all those who take an interest in the developments of

modern physics and seek some simpler explanation of worlds which are always expanding but never burst.

Mr. Tomkins, the little clerk of a big city bank, tired and bored by the monotony of addition of columns of bank accounts, decides to attend lectures on Relativity of Space and Time, Curved Space and Gravitation and the quantum of action. The only π he knows has a crust on it and his λ's were cuts from the joint. It is not surprising that he should fall asleep and dream. As in so many dreams the impossible suddenly became quite understandable and this is where Professor Gamow so ably interprets his lectures for bank clerks and all that vast army who handle far less money than bank clerks do, but who are always wanting to learn of the exciting things around them.

Mr. Tomkins, in his dream, visits the toy universe where the speed of light is only about 75 m.p.h., gravity is a million million times that of the earth's and the universe expands and contracts every two hours and in it he begins to understand the expanding universe in which he really lives. The quantum room of his second dream provides a shock. He learns that solid objects may leak through walls and he decides to keep clear of the Zoo in future in case a lion or a tiger leaked through. In his third dream the velocity of light has dropped to ten m.p.h. Mr. Tomkins rides a bicycle in this new world and sees other people riding bicycles. They became inconceivably flattened in the direction of motion, and as he rode his bicycle streets became shorter, the windows of shops looked like narrow slits and the policeman on the corner became the thinnest man he had ever seen.

But even Mr. Tomkins jibbed a little when he found that the more you travelled in this world the younger you got. Grandfather, who travelled widely, looked like his granddaughter's son because he didn't travel at all. The fourth dream of Mr. Tomkins shook him rather badly. He rode on a quantum elephant and was attacked by a quantum tiger which was only killed by " raising the Hamiltonian."

" This is a rough world," explains the Professor, " where no gentle action is possible. If a person in such a world tried to pat a kitten, it would either not feel anything at all, or its neck would be broken by the first quantum of caress."

I like that expression " quantum of caress." There are many people in this more ordinary of ordinary worlds who could do with a quantum of caress, although, the censorship being what it is, no names may be mentioned.

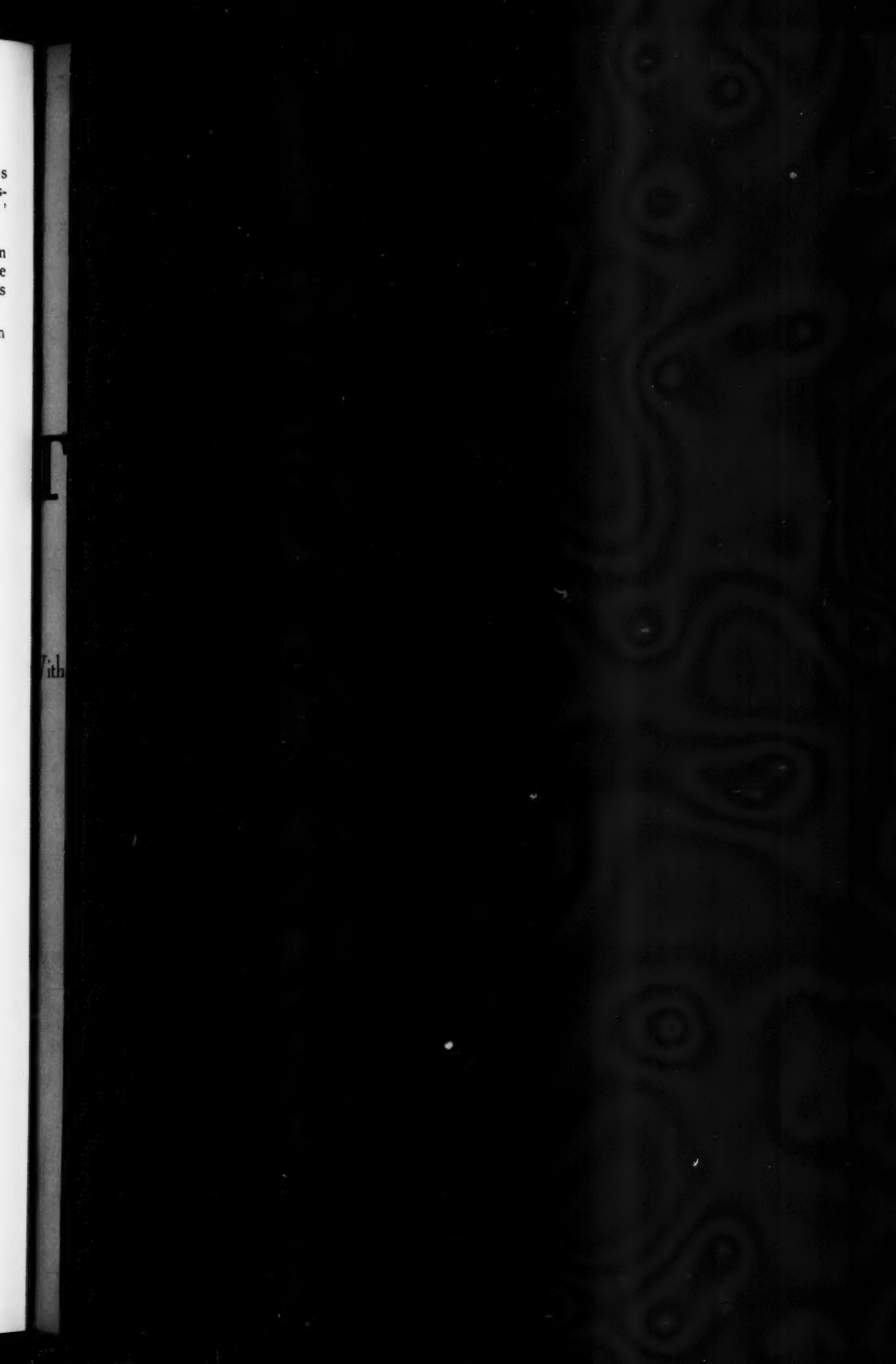
When, in the quantum wood, Mr. Tomkins saw a group of gazelles approaching their elephant, his professor guide remarked, " Do not waste your cartridges. There is very little chance of hitting an animal when it is moving in a diffraction pattern." The worst part of the quantum wood was the quantum mosquito, which could scarcely be located at all, despite the comparatively large value of the quantum constant. Still it had a quantum sting all right and no wonder the natives in the district thought the quantum wood was populated by devils.

Dream stories, yes, with exaggerated physical constants which serve to explain the remarkable theories of the world's leading physicists and make them intelligible, if not true.

Professor Gamow's original lectures are printed as an appendix to the dreams of Mr. Tomkins. I cannot refrain from making one quotation from his lecture on the quantum of action. For those who do not understand the terms used they might be reading the adventures of Alice.

" It is clear that, if we cannot in general define the position of a material particle by a mathematical point and the trajectory of its motion by a mathematical line because the things had spread out, we should use other methods of description giving, so to speak, ' the density of the gruel ' at different points

of space. Mathematically it means the use of continuous functions (such as are used in hydrodynamics) and physically this requires us to be used to expressions like ' this object is mostly here, but partially there and even yonder ' or ' this coin is 75 per cent. in my pocket and 25 per cent. in yours '."

One suspects that the Chancellor of the Exchequer is a student of the quantum theory and has been increasing the value of the quantum constant rapidly in the last few months. At any rate, it is certain that only 25 per cent. of any coins the reviewer may have are in his pocket and 75 per cent. in the Chancellor's.

Buy the book and learn how lucky you are not to be a miserable electron that has to be all round the nucleus at once.